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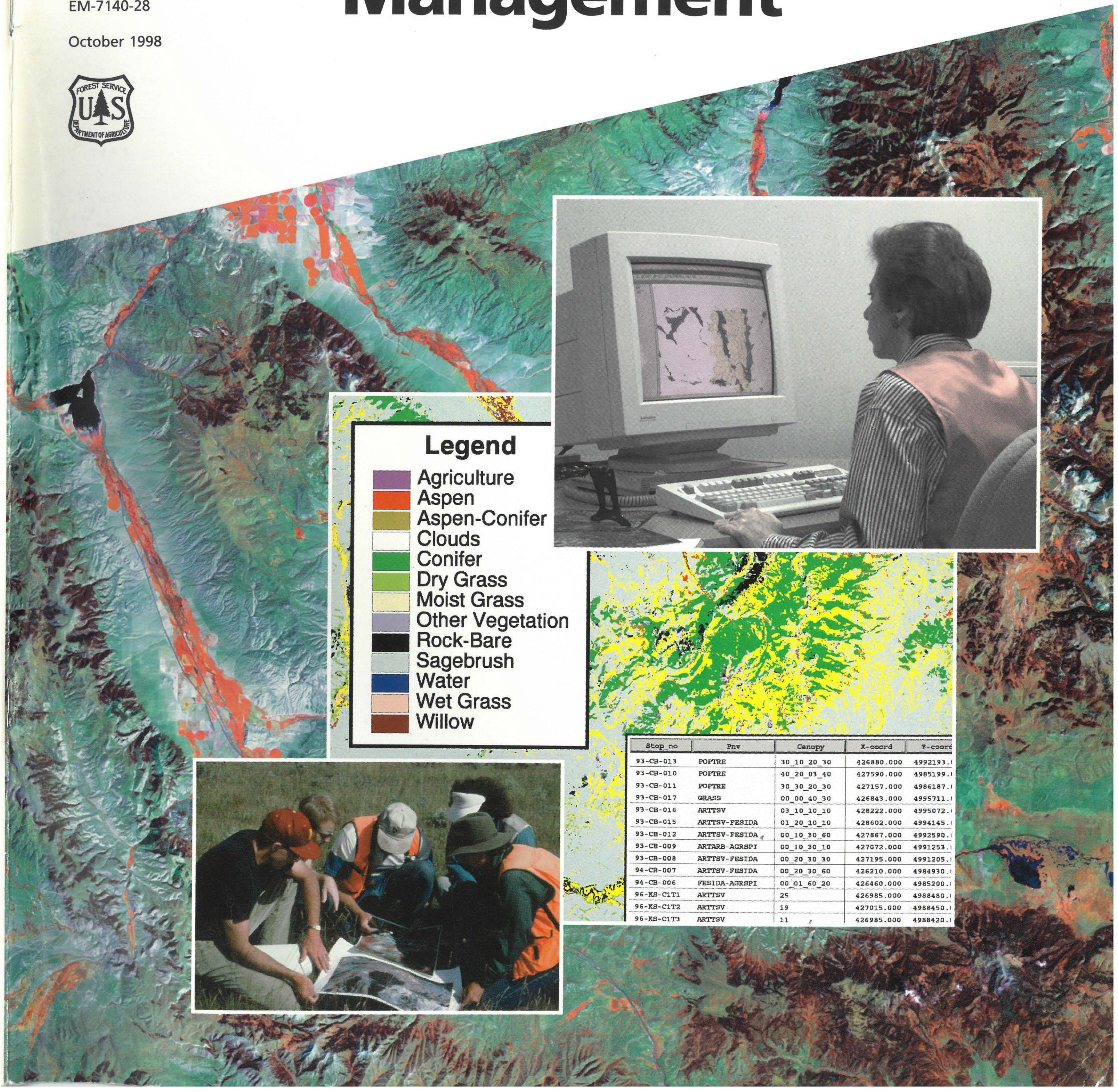
Legend
Agriculture
Aspen
Aspen-Conifer
Clouds
Conifer
Dry Grass
Moist Grass
Other Vegetation
Rock-Bare
Sagebrush
Water
Wet Grass
Willow

Stop_no	Pnv	Canopy	X-coord	Y-coor
93-CB-013	POPTRE	30_10_20_30	426880.000	4992193.
93-CB-010	POPTRE	40_20_03_40	427590.000	4985199.
93-CB-011	POPTRE	30_30_20_30	427157.000	4986187.
93-CB-017	GRASS	00_00_40_30	426843.000	4995711.
93-CB-016	ARTTSV	03_10_10_10	428222.000	4995072.
93-CB-015	ARTTSV-FESIDA	01_20_10_10	428602.000	4994145.
93-CB-012	ARTTSV-FESIDA	00_10_30_60	427867.000	4992590.
93-CB-009	ARTARB-AGRSPI	00_10_30_10	427072.000	4991253.
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96-KS-C1T3	ARTTSV	11	426985.000	4988420.

Implementation of Remote Sensing for Ecosystem Management

Prepared for
Interregional Ecosystem Management Coordinating Group
and
Remote Sensing Steering Committee

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1. Executive Overview

Remotely sensed imagery is an important source of current and repeatable information about the location, quantity, and quality of land cover. Remote sensing also establishes a base from which to monitor changes over time. The Interregional Ecosystem Management Coordinating Group (IREMCG) has sponsored a consolidated procurement of satellite imagery for the conterminous United States. This imagery consists of: Advanced Very High Resolution Radiometer (AVHRR), Landsat Multispectral Scanner (MSS), and Landsat Thematic Mapper (TM). This multiresolution and multitemporal satellite imagery was purchased to assist in field implementation of remote sensing to support ecosystem management, with an emphasis on large area assessments and forest plan revisions.

Guidelines and recommendations are needed to properly use the satellite imagery purchased by the IREMCG. This document provides an overview of current procedures in use and makes recommendations to assist with vertical and horizontal integration of geospatial information derived from remote sensing, and to facilitate the flow of data between large area assessments, forest plan revisions, and individual projects. These guidelines and recommendations are based on governmentwide Federal standards for content and accuracy of geospatial data currently being established by the Federal Geographic Data Committee (FGDC).

This document describes current applications of remote sensing within the Forest Service, and includes examples of how remotely sensed data are used to derive resource information at various scales defined by the National Hierarchical Framework of Ecological Units. It also discusses general guidelines and image processing procedures to classify vegetation types and to create change detection products (from satellite imagery). The document recommends ways to develop consistent products, lists skills and training requirements, and identifies the need for a spatial data clearinghouse. The recommendations are not intended to limit the way Forest Service remote sensing projects are designed or implemented. These recommendations will facilitate data sharing and distribution, reduce duplication of effort, and promote consistent Geographic Information System (GIS) Core Data. Some projects or planning efforts may require a more detailed classification scheme to meet specific objectives. Projects need to be designed so derived data and products can be cross-referenced to the recommended attributes.

The IREMCG sponsored and provided direction for the development of this document. Partial funding was provided by the Remote Sensing Steering Committee (RSSC). This document was prepared by the staff at the Remote Sensing Applications Center (RSAC) and the Remote Sensing Advisory Team, which represents a cross-section of Forest Service managers and resource specialists.

1.1 Summary of Recommendations

The IREMCG recommends that the following standards and procedures for the use of remotely sensed data be adopted Service-wide. For more detailed descriptions of the following recommendations, the reader is referred to section 8.

Nonvegetative Land Cover Classes

Use portions of the USGS Land Use/Land Cover Classification System (Appendix E) to describe predicted nonvegetative land cover attributes.

Vegetative Land Cover Classes

Define the predicted land cover classes by four attributes: canopy structure, tree size class, percent crown closure, and vegetation composition. The National Vegetation Classification System (NVCS) as defined by the FGDC Vegetation Subcommittee is recommended for defining vegetation composition. The adoption of this system will improve horizontal and vertical data integration and promote interagency data sharing. Using the NVCS will ensure compliance with Executive Order 12906 (section 3, "The Need for Consistent Products From Remote Sensing").

Metadata

Use the "Content Standard for Digital Geospatial Metadata" developed by the FGDC for documentation and archive purposes.

Clearinghouse

Establish a clearinghouse within the existing Forest Service Intranet for collection and dissemination of remote sensing data, products, and reports.

Training

Determine a "core competency" requirement with respect to remote sensing awareness and implementation for all natural resources staff and line management. Ensure, through individual development plans, that the personnel receive training needed to meet these requirements.

Develop a training program to meet the skill requirements of designated image analysts and GIS Core Data technical staff at the national forest level. Identify opportunities for background strengthening and skills improvement, and ensure that critical personnel receive training needed to meet the identified requirements.

Technical Support

Establish a help desk (intranet and telephone-based) to supply technical and user application support for the Forest Service image processing system and GIS Core Data.

Sections 4, 5, 6, and 7 describe applications, guidelines, and procedures to develop consistent products from remotely sensed data.

2. Overview of Remote Sensing in the Forest Service

2.1 Definition of Remote Sensing and Image Processing

Remote sensing is gathering data about an object or event from a distance. What is observed, how the data are recorded, and from what distance the data are gathered vary considerably (figure 2.1). An aerial photo is an example of remotely sensed data (figure 2.2). Aerial photos may be acquired with different film/filter combinations, at various scales, and at different times of the year. They record data about the current state of the vegetative cover and numerous other physical and physiographic conditions.

Figure 2.1. *GPS data is often used to support remote sensing and GIS.*

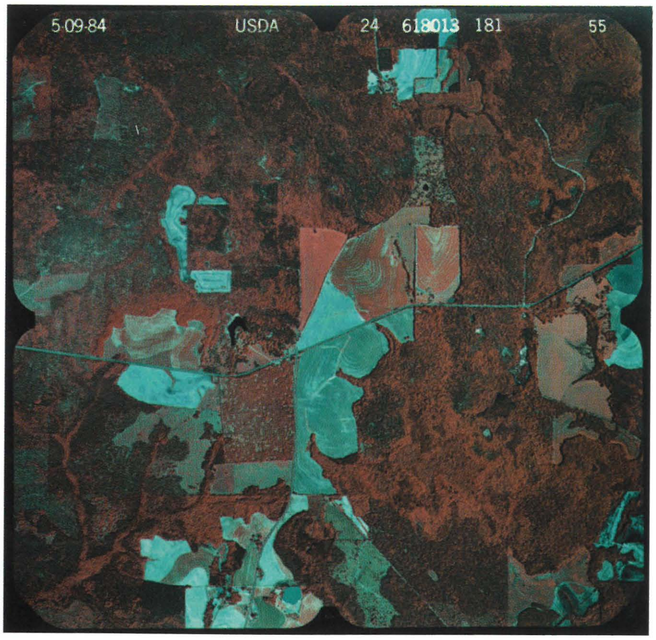


Figure 2.2. *Color-infrared aerial photo of an area in southern Alabama.*

Remotely sensed data can also be gathered in a digital format. Examples of digital remote sensing systems include the Landsat Thematic Mapper (TM) (figure 2.3) or Advanced Very High Resolution Radiometer (AVHRR). Digital remotely sensed data have been widely used for research purposes and are now gaining acceptance as an essential tool for ecosystem management. Several factors, including the low cost per acre, the synoptic view of a large area, and the ability to acquire data on a repeatable cycle, make digital remotely sensed data particularly well suited to ecosystem management.

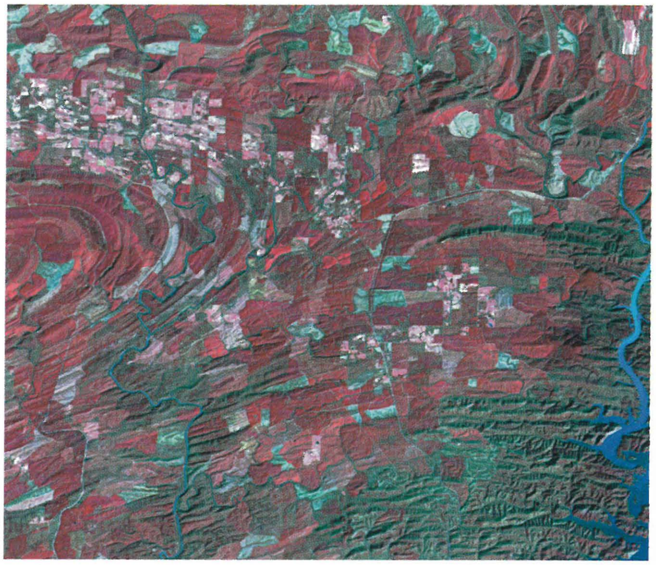


Figure 2.3. *Subset of a Landsat TM scene over Broken Bow Lake, Oklahoma. Color-infrared is depicted using bands 4, 3, 2.*

Image processing is the digital manipulation of remotely sensed data to create a desired product or extract specific information (figure 2.4). Image processing is generally applied on digital satellite data, but may use other remotely sensed information, such as scanned aerial photographs or images captured by a digital frame camera, radar sensor, or multispectral scanner. Computers and image processing software analyze the digital data, as opposed to the manual interpretation of aerial photos. Forest vegetation classification, identification of ecosystem disturbance, delineation of specific wildlife habitats, and change detection products can be produced from image processing.

2.2 History of Remote Sensing in the Forest Service

Early remote sensing efforts within the Forest Service used aerial photography. The agencywide acceptance of aerial photos as a management tool is due to their historical use and availability. Military applications of aerial photo interpretation were adopted by the Forest Service in the 1920's to assist in managing forest pests and monitoring forest fires. During World War II, color-infrared photography was developed for camouflage detection; later the Forest Service used it for forest disease detection and vegetation mapping. In

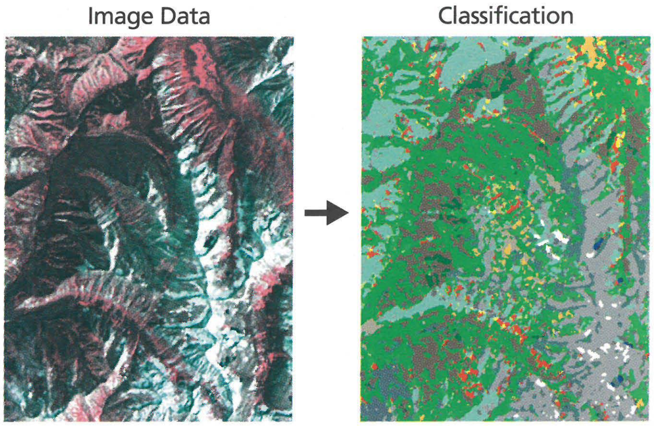


Image Data

Classification

Figure 2.4. *Landsat TM imagery and corresponding land cover classification of an area within the Sawtooth National Forest, Idaho.*

1946, the Aerial Survey Research Project was established at the Beltsville National Agricultural Research Center to aid forest insect and disease research within the Forest Service. Other extensive remote sensing programs were established at the Pacific Southwest Experiment Station and later at the Rocky Mountain Forest Experiment Station. Many World War II veterans with aerial photo interpretation skills were employed by the Forest Service after the war. The space race of the 1950's and early 1960's led to the launch of the TIROS-1 meteorological satellite, an early source of digital, nonphotographic, remotely sensed data. In its quest for applications for this data, NASA turned to the natural resource community. Landsat, the next generation of satellites, was specifically designed to gather multispectral data on the Earth's land areas in a consistent, recurring cycle. These multispectral data were collected in the visible and near-infrared portions of the electromagnetic spectrum (figure 2.5).

Forestry and agricultural researchers were able to use the multispectral data to evaluate large areas using these data sets collected at single points in time. The repeatability, continuity, and wide availability of digital satellite imagery contributed to the current development of remote sensing, image processing, and Geographic Information Systems (GIS) technologies.

In the 1970's the Forest Service established the Nationwide Forestry Applications Program (NFAP), now called the Remote Sensing Applications Center (RSAC) at NASA's Johnson Space Center to work on forestry-related applications of the Landsat program and other airborne programs. RSAC, a detached unit of the Washington Office Engineering Staff, is co-located with the Forest Service's Geometronics Service Center (GSC) in Salt Lake City, Utah, and continues its liaison activities with NASA, other agencies, universities, and commercial remote sensing firms. RSAC is organized into four program areas to provide technology evaluation, development, and training support in the use of remote sensing, GIS, image processing, and the Global Positioning System (GPS) for all resource applications. Each Forest Service Region has a geometronics group that is responsible for supporting remote sensing projects within that specific region.

Because the early Landsat data proved so valuable for natural resource applications, NASA continued to develop additional advanced sensors. Analysts determined that bands 1 and 2 of AVHRR data could be used for continental vegetation studies (figure 2.6). NASA also continued to support and upgrade the Landsat program, adding the TM sensor to Landsat-4. Landsat TM data are widely used for vegetation studies today. Several other countries have also launched remote sensing satellite systems. The French operate Système Pour l'Observation de la Terre (SPOT), which gathers panchromatic images in addition to multispectral data. Japan, India, and Canada have recently launched satellites as well. Numerous private and commercial ventures have plans to put sensors in orbit to fill the demand for high-resolution remotely sensed data. See appendix A for specific information about current and planned remote sensing systems.

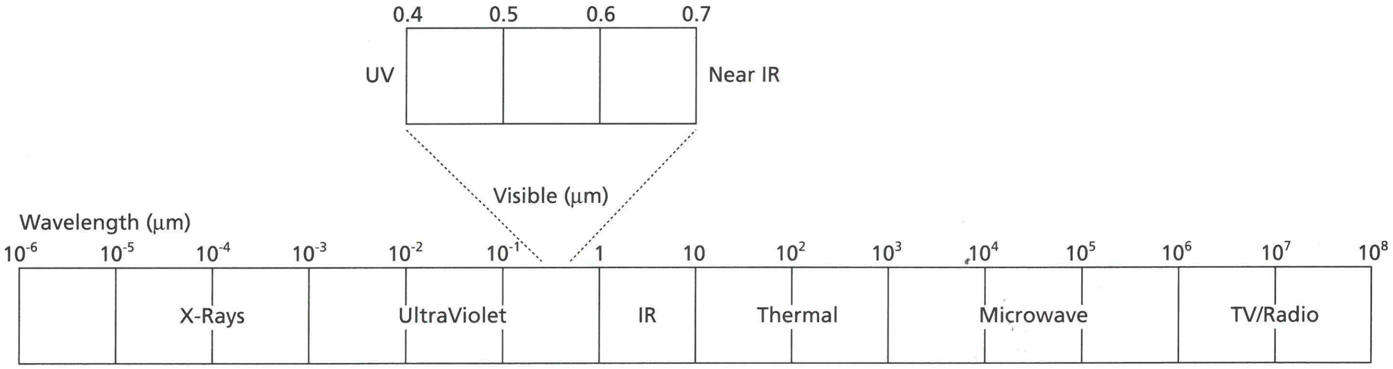


Figure 2.5. *Visible energy makes up only a small fraction of the entire electromagnetic spectrum. Many remote sensing instruments can record information in the IR and thermal portions of the spectrum as well (Maus et al., 1995).*

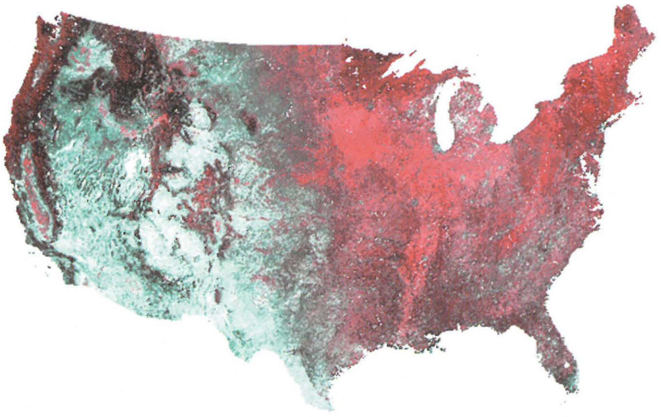


Figure 2.6. *AVHRR image mosaic for the conterminous United States.*

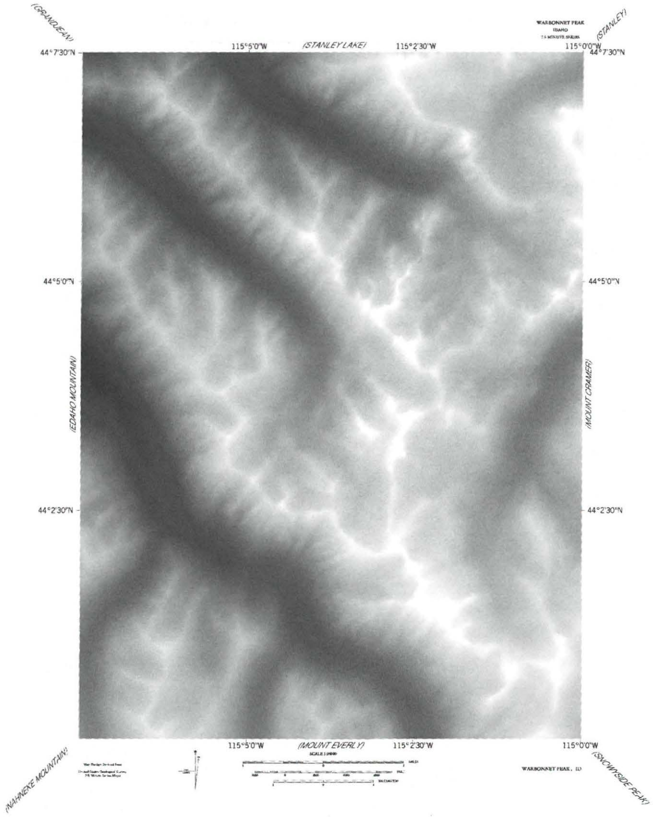


Figure 2.7. *Image product from a digital elevation model of part of the Sawtooth National Forest, Idaho.*

2.3 Current Remote Sensing in the Forest Service

The reliance of Forest Service managers and resource specialists on aerial photos has not diminished with the proliferation of digital remote sensing technology in recent years. Aerial photos are an important source of ancillary data for classifying satellite images. Digital photos are made by scanning an aerial photo and correcting for distortion. Many commercial image processing packages available today have modules specifically designed to analyze scanned photos. Advanced stereo compilation tools are used for photogrammetric surveys and engineering applications.

These digital photos are used to produce digital orthophoto quads (DOQ's) and may be used to generate digital elevation models (DEM's). Figure 2.7 is a graphic representation of the results of an analysis of a DEM.

DOQ's combine the image characteristics of an aerial photo with the geometric qualities of a map. A DEM consists of raster data where pixels represent elevation rather than reflectance. For more detailed descriptions of DOQ's and DEM's, refer to appendix A. The wide availability of digital satellite data and limited availability of computer software to process it spurred the development of image processing software. Many of the early programs required expensive computer systems that were not readily available to land management agencies. In the mid-1980's, there were only three known image processing systems being used by the Forest Service. New software, combined with the rapid growth and development of computer technology, will enable most resource managers to analyze digital remotely sensed data.

In 1991, 19 image processing licenses, using five separate software systems, were in use within the Forest Service. By 1994, the number had risen to more than 100 licenses of 13 different software systems, located in Regional, forest, and district offices (based on a 1994 questionnaire and data from vendors). The Forest Service is currently implementing a standard configuration of IBM computer hardware and software for office automation and managing resource information. The Forest Service IBM system includes ARC/INFO GIS to manage geospatial data. In the near future, the Forest Service plans to add image processing software to the IBM system, which will enable Service-wide capability and facilitate remote sensing management and information exchange.

Two developments, additional image processing systems within the Forest Service and maturation of this technology, have moved digital remote sensing from primarily a research tool to an operational capability. Resource managers and researchers use remotely sensed data from a variety of sources, including aerial photos and digital satellite images, to address ecosystem management issues. Other remote sensing and data collection systems include radar, GPS (figure 2.8), airborne video, forward looking infrared (FLIR) systems, and digital color-infrared cameras (figure 2.9).

Remotely sensed data and image processing systems are tools used to derive geospatial data layers from digital information. The development of these data layers (for example, a vegetation map derived from a multivariate classification) typically involves an integrated approach, which entails using other geospatial data layers (such as DEM's, slope, aspect, soil, and hydrography), along with remotely sensed data, to model a specific phenomenon such as vegetation composition. This integrated approach results in higher classification accuracy than when remotely sensed data are used alone.

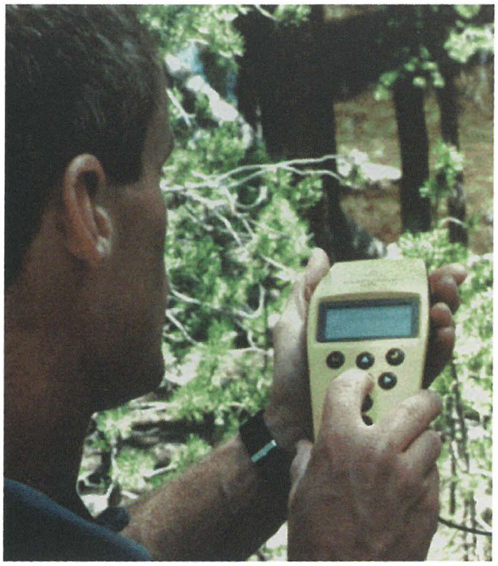
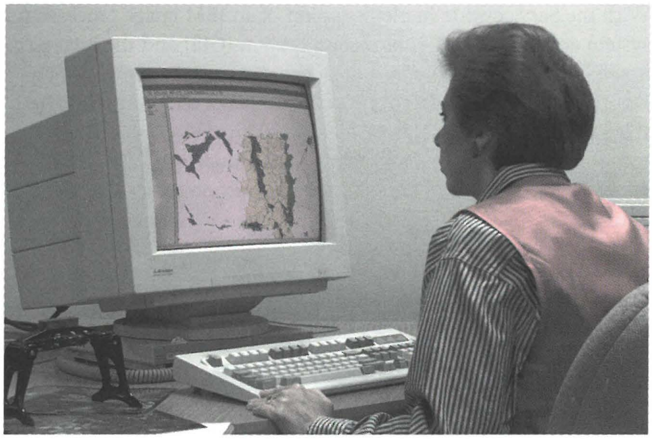


Figure 2.8. *Hand-held GPS unit.*

Nikon
N90
Kodak
DCS 420
DCS

Figure 2.9. *Digital color-infrared camera system.*

This integrated modeling approach demonstrates the relationship between remotely sensed data and other types of geospatial data layers used to assist in the development of GIS Core Data. GIS Core Data contain consistent data layers for all national forests and include geospatial data developed from various sources (for example, remote sensing and GPS). Another key element of GIS Core Data is that they must contain consistent attribute features. This ensures that all data layers have a common set of baseline data, thereby providing a flexible data base to meet current and future information needs of the Forest Service (Warbington *et al.*, 1993). Additionally, this facilitates data sharing within the Forest Service.



2.4 Examples of Past and Current Remote Sensing Projects in the Forest Service

Here is a brief selection of remote sensing projects undertaken by the Forest Service since the late 1980's.

- Monitoring defoliation by the spruce budworm using high-altitude color-infrared aerial photography.
- Detecting subsurface gravel deposits using multispectral thermal infrared imagery.
- Locating cave openings using thermal infrared imagery.
- Mapping vegetation in all the national forests in California, Oregon, and Washington using Landsat TM.
- Mapping vegetation in the Southern Appalachians using Landsat TM.
- Supporting the goals of 1993 Resource Planning Act (RPA) using AVHRR and Landsat TM.
- Supporting Regional forestland inventories using AVHRR and Landsat TM.
- Detecting change in forestland using Landsat TM.
- Mapping wetland types using aerial photos and Landsat TM.
- Using Landsat TM to enhance cartographic products.
- Using SPOT to detect gypsy moth damage.
- Using SPOT as a replacement for orthophotos, vegetation updates, and Cartographic Feature File (CFF) updates.
- Mapping forest fires using airborne thermal infrared imagers.
- Assessing wildfire severity using Landsat TM and other data gathered with airborne digital sensors.
- Using AVHRR to predict forest fire potential.
- Assessing range conditions with airborne video.
- Using GPS to collect resource data for use in GIS and to provide control for satellite imagery.
- Mapping fires with GPS.

Ecosystem management often requires extensive resource information about large geographic areas. Remotely sensed data, combined with ancillary information, satisfies these requirements to support ecosystem management activities.

3. The Need for Consistent Products From Remote Sensing

With the Service-wide implementation of an IBM image processing system and Geographic Information System (GIS) and the increased availability of remotely sensed data, users at most levels within the Forest Service will be able to process geospatial data. It is essential that guidelines be established to ensure the development of consistent products, facilitate data sharing, and reduce duplication of effort. Horizontal integration and vertical integration are crucial to consistent analysis and manipulation of remotely sensed data (figure 3.1).

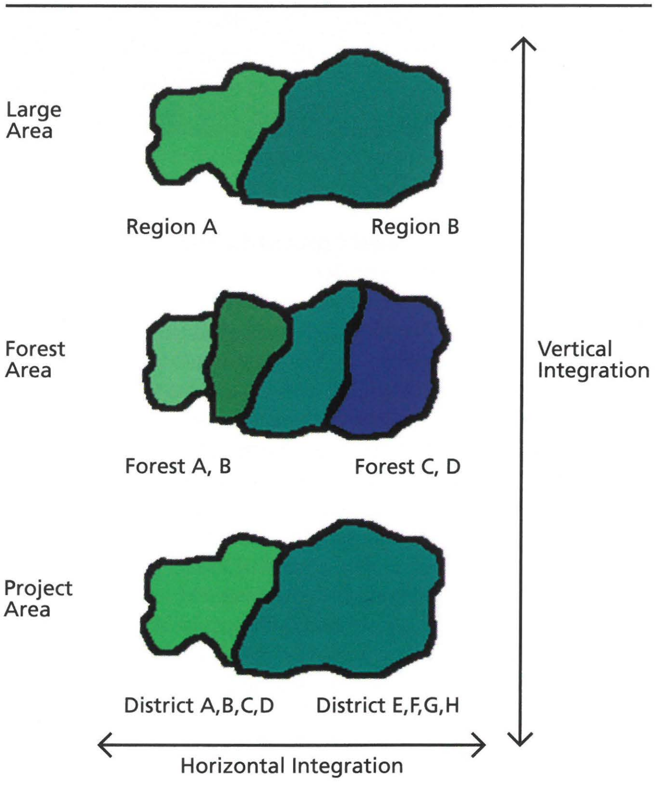


Figure 3.1. *Integration of remotely sensed data for ecosystem management.*

With vertical integration, data gathered at the project level can be collapsed to fit into area classes above it. Downward integration is not always possible due to limits on the way the data were collected (that is, the spatial resolution, classification method, or size of minimum mapping unit). Horizontal integration allows for data sharing among districts, forests, or Regions at the same ecological level across geographic areas. For example, the Remote Sensing Lab in Region 5 developed a standard GIS Core Data set for every national forest in the Region. Part of this data set is a vegetation layer (Classification and Assessment With Landsat of Visible Ecological Grouping, or CALVEG) with standardized classes. Consistent classification schemes and methodologies were used to create a vegetation layer for each national forest (that is, horizontal integration). Moreover, the CALVEG standard data set could be used for the next national Resource Planning Act (RPA) assessment. CALVEG classes would be cross-referenced to less detailed RPA classes (that is, vertical integration).

The digital satellite data sets purchased by the Interregional Ecosystem Management Coordinating Group (IREMCG) consist of Advanced Very High Resolution Radiometer (AVHRR) mosaics, Landsat Multispectral Scanner (MSS) triplicates, and Landsat Thematic Mapper (TM) imagery for the conterminous United States. Their different spatial resolutions allow for analysis across various physiographic scales. AVHRR data are suitable for vegetation assessment at the Regional scale because of their spatial resolution of 1.1 km and large area of coverage (figure 3.2). The Landsat MSS triplicates have been co-registered and resampled to 60-meter resolution. They were acquired during the 1970's, 1980's, and early 1990's (figure 3.3). These triplicates are valuable for change detection studies at the subregional level. The 30-meter-resolution Landsat TM data are effective for a broad range of ecosystem management applications, large area assessments, and forest plans (figure 3.4). IREMCG Remote Sensing Coordinators are maintaining the repository for this data set. See appendix I for a list of coordinators.

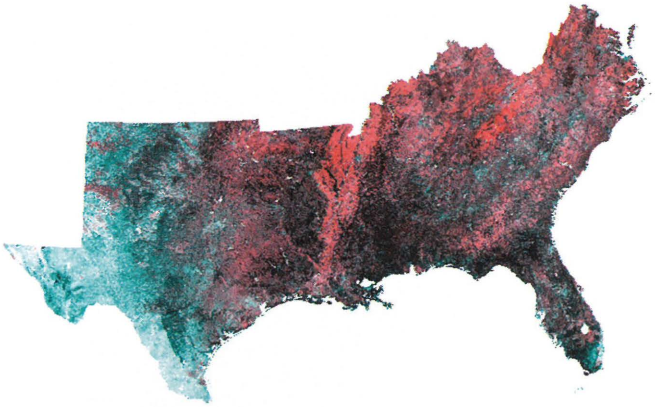
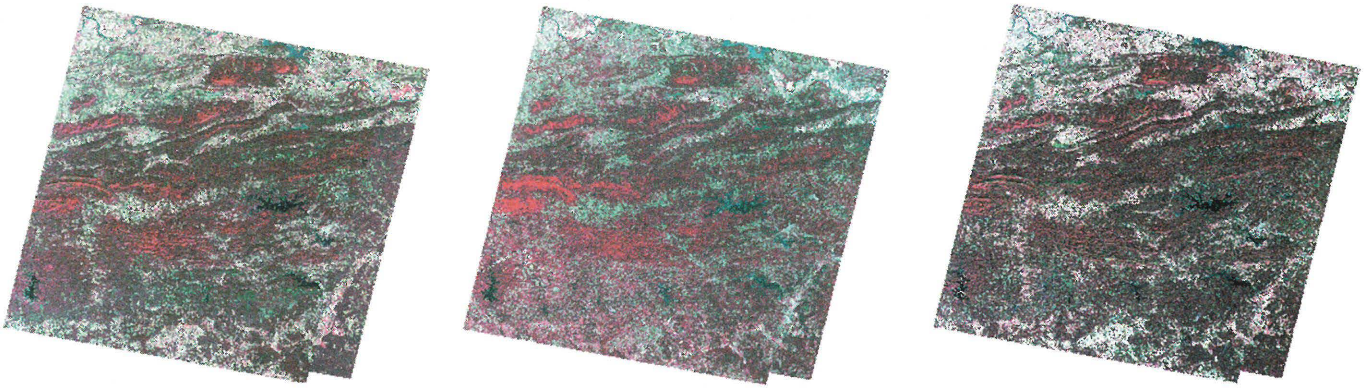


Figure 3.2. *AVHRR mosaic of the southeastern United States.*

The need to coordinate and share geospatial data with other Federal, State, and local agencies is an incentive to develop products and resource information consistently. Executive Order 12906 established the National Spatial Data Infrastructure (NSDI) to foster more efficient use, management, and production of geospatial data by Federal, State, local, and tribal governments. The Federal Geographic Data Committee (FGDC) coordinates development of the NSDI. The committee's activities include establishing a baseline set of spatial features, formalizing standards for digital geospatial data, and creating a clearinghouse to facilitate the sharing, evaluation, and distribution of the data.



October 4, 1972

July 8, 1984

October 8, 1991

Figure 3.3. *Set of MSS triplicates over southwest Arkansas. Each image covers approximately 7.5 million acres.*

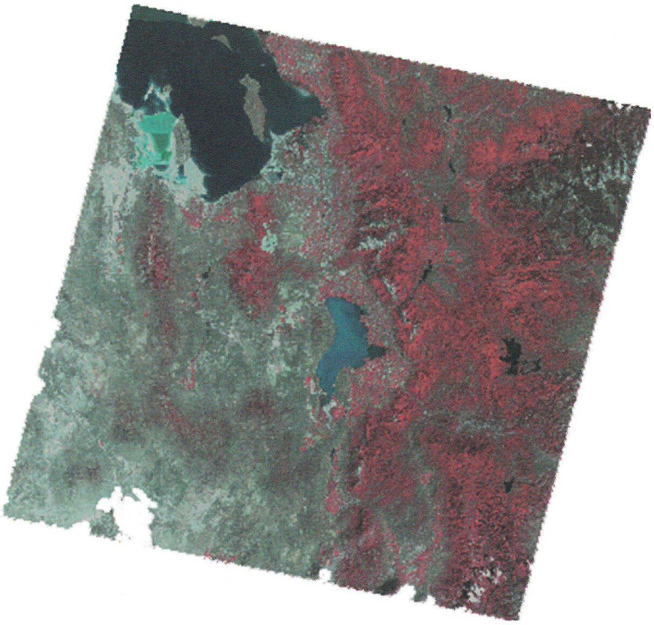


Figure 3.4. *Full Landsat TM scene over Salt Lake City and a portion of the Wasatch mountain range. Each Landsat TM image covers approximately 7.5 million acres.*

4. Remote Sensing at Multiple Levels

Effective ecosystem management requires information from many sources on many levels. Acquiring the necessary data in a timely and cost-effective manner is a great challenge to resource managers. Even basic information such as type, location, and relationship to other ecosystems is difficult to collect due to the vast amounts of data needed and the complex interrelationships in natural environments. The Forest Service, along with other Federal agencies, has renewed its effort to collect and analyze the information needed to understand ecosystems and manage natural resources more objectively.

To succeed, resource managers must clearly understand how ecosystems work and relate at varying levels. Ecosystem processes function at local, regional, and global scales simultaneously. The National Hierarchical Framework of Ecological Units was developed to define these processes at different scales (table 4.1). An ecological unit is the basic category for ecosystems having similar response potential and resource production capability at a particular scale (Avers *et al.*, 1993). Defining units at a variety of scales allows resource managers to address the complex questions of ecosystem management more clearly.

Determining boundaries is a challenge, particularly for broad-scale ecological units. To define and understand the units and their interactions, it is necessary to collect data over large areas simultaneously. The synoptic view provided by remotely sensed data is a partial solution to this problem. Additional information can be derived from Geographic Information System (GIS) data bases.

Various types of remotely sensed data are currently available to delineate and analyze ecological units at one or more levels of the National Hierarchy (table 4.2). The spatial and spectral resolution of the sensor typically determines the level at which the data can be applied. Coarse spatial resolution is best suited for exploring ecological units at the broad ecoregional scale. Creating more detailed maps of smaller ecological units requires higher spatial resolution. For example, a national mapping effort to study large, generalized ecological units over millions of acres would most likely use image data provided by the Advanced Very High Resolution Radiometer (AVHRR) sensor. However, landtype associations, which are in the tens to hundreds of acres in size, would be depicted using data provided by the Landsat Thematic Mapper (TM), the Système Pour l'Observation de la Terre (SPOT), or a large number of aerial photos.

Table 4.1. *The National Hierarchy of Ecological Units.*

Planning and Analysis	Ecological Units	Purpose, Objectives, and General Use	General Size Range
Ecoregion Global Continental Regional	Domain Division Province	Broad applicability for modeling and sampling; Large area planning and assessment; International planning	Millions to ten thousands of square miles.
Subregion	Section Subsection	Strategic, multiforest, statewide, and multi-agency analysis and assessment	Thousands to tens of square miles
Landscape	Landtype Association	Forest or areawide planning and watershed analysis	Thousands to tens of acres.
Land Unit	Landtype Landtype Phase	Project and management area planning and analysis	Hundreds to less than ten acres.

Table 4.2. *Relationship of remotely sensed data to the National Hierarchy of Ecological Units.*

Ecological Level	Ecoregion	Subregion	Landscape	Land Unit
Remote Sensing Data	AVHRR, MSS	MSS, TM, photos[1]	TM, SPOT, photos[1]	SPOT, photos[2]
Local Accuracy	1 km - 100m	100 m - 30 m	30 m - 10 m	< 10 m
Feature Size	100s of km	10 ha	1 ha	< 1 ha
Scale	1:5,000,000 or smaller	1:5,000,000 to 1:250,000	1:250,000 to 1:50,000	1:50,000 or larger

[1] Small-scale aerial photos > 1:40,000
[2] Medium-scale aerial photos 1:40,000 to 1:15,000

4.1 Ecoregion

Ecological units for the entire United States have been developed at the broadest level (figure 4.1). Ecoregions are subdivided into domains, divisions, and provinces (Bailey, 1996). Domains and divisions are defined primarily by climatic factors. Latitude, continental position, and elevation influence climate. Vegetation macrofeatures determine when divisions are broken into provinces. AVHRR is a good choice for assessing ecosystems at these levels. The AVHRR sensor collects multispectral data and has a 2,400-kilometer swath width and 1-kilometer spatial resolution. Therefore, it can be used to evaluate vegetation and landforms throughout an ecoregion.

4.2 Subregion

Next in the hierarchy are subregions, which are further divided into sections and subsections (figure 4.1). Regional environmental factors, such as geomorphic processes, topography, and climate, influence the determination of subregions. Projects conducted over a number of forests or across a State are subregional. Sensors with midrange spatial resolution, Landsat TM, are appropriate for this level. Additionally, some small-scale, high-altitude aerial photos would be useful to map and analyze vegetation.

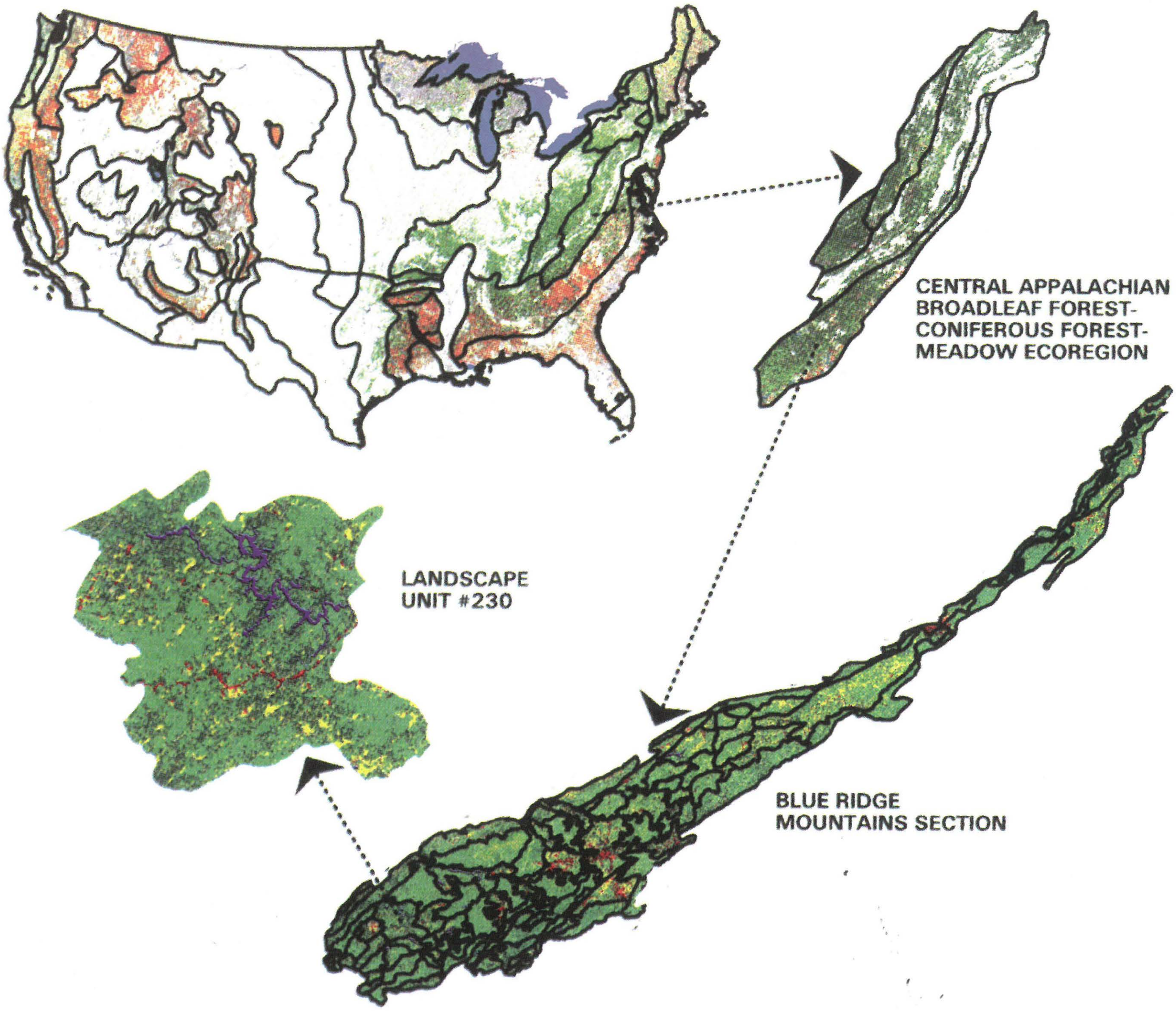


Figure 4.1. *Ecoregions have been delineated for the conterminous United States. Ecoregions are broken down into sections. Some large area assessments have further divided sections into landscapes, as depicted here for the Southern Appalachian Assessment.*

4.3 Landscape

Landtype associations are mapped at the landscape level (figure 4.1). General topography, geomorphic processes, surficial geology, type of soil, local climate, and potential natural communities determine landtype association boundaries. At the landscape level, forest or watershed assessments are possible using Landsat TM, SPOT, and aerial photos. The 185-kilometer swath width and 30 meter spatial resolution of Landsat TM imagery make it useful for both subregional and landscape studies. The moderate swath width provides a synoptic view of a large area, and the midlevel spatial resolution supplies significant detail about vegetation or land cover conditions.

4.4 Land Unit

Land units are the building blocks of landtype associations and are described as either landtypes or landtype phases. At this scale, local topography, rock and soil types, and vegetation determine unit descriptions and boundaries. Landtypes and landtype phases are used for managing and planning at the forest or project level. High-resolution remotely sensed data are combined with Digital Elevation Models (DEM's), field data, large-scale aerial photos, and expert local knowledge to describe ecological units at this level.

4.5 Examples

4.5.1 Ecoregion Level

1993 Resource Planning Act Forest Type Group Map

Innovative modeling procedures produced two forest cover data sets for the entire United States from AVHRR data (Zhu and Evans, 1994). A predicted percent forest cover map was created by modeling the percent forest cover per square kilometer (figure 4.2) (Zhu, 1994). The forest type group map depicts the spatial distribution of 25 forest cover types (figure 4.3). The maps were made as part of the 1993 Resource Planning Act (RPA) assessment update (Powell et al., 1993). Researchers were able to link regional Forest Service Forest inventory and analysis (FIA) data to the images to identify regional vegetation patterns. For example, the FIA data showed a transition of pine to upland hardwoods in Alabama over the past two surveys. The forest type group map depicted a related transitional zone between the loblolly-shortleaf type and the oak-hickory and oak-pine types. Zhu and Evans (1994) reported that the RPA classification of forest type groups is not always responsive to analysis with remotely sensed data. They recommended a hierarchical system to facilitate comparison of classification results from projects at different physiographic levels.

Table 4.3 provides cost estimates for the RPA Forest Type Group Mapping Project. These estimates assume experienced remote sensing and GIS analysts are available so that projects are immediately operational with no time required for training.

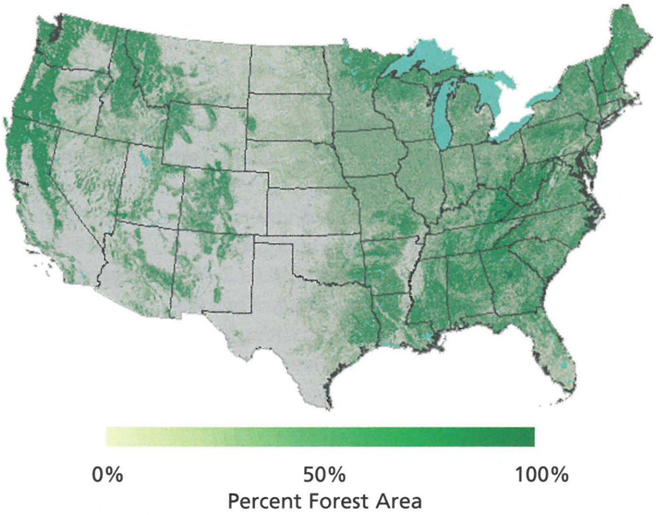


Figure 4.2. *Predicted percent forest area per square kilometer for the conterminous United States.*

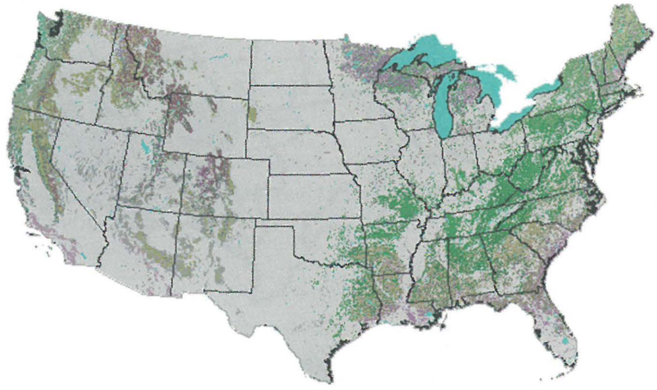


Figure 4.3. *Forest type group map for the conterminous United States.*

Table 4.3. *Cost estimates for the RPA Forest Type Group Mapping Project.*

Time		
	Remote Sensing Analyst	2 years @ full time
	Associate Analyst	.5 years @ full time
Expenses		
	Data	$95,000
	Other[1]	$20,000

[1] Includes but not limited to field data collection, office supplies, computer storage, travel, and publication costs.

For further information on the RPA Forest Type Group Mapping Project, visit the Southern Research Station Forest Inventory and Analysis web page at srsfia.usfs.msstate.edu/rpa/rpa93.htm. The data for figures 4.2 and 4.3 can also be downloaded at this site.

Gap Analysis Program

The Gap Analysis Program (GAP) is compiling information on a State-by-State basis to identify gaps in biodiversity protection (figure 4.4). GAP land cover maps are effective for conservation planning at the local and regional levels (Stoms et al., 1994).

Three data layers are employed in a GAP:

- Distribution of actual vegetation types;
- Land ownership; and
- Distribution of terrestrial vertebrates.

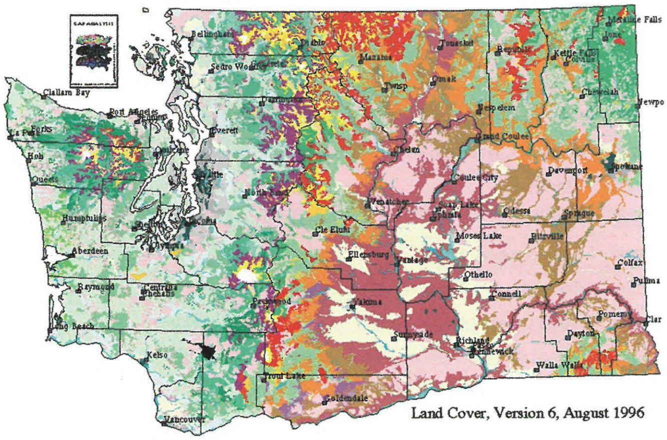


Figure 4.4. *GAP land cover data for Washington State.*

The distribution of vegetation types is determined from Landsat TM imagery. Complete coverage of the conterminous 48 States was acquired under the Multi-Resolution Land Characteristics Consortium (MRLC). The imagery was pre-processed, archived, and distributed by the USGS Earth Resources Observation System Data Center (EDC).

The National GAP standards specify that vegetation types be consistent with the United Nations Educational, Scientific, and Cultural Organization/The Nature Conservancy (UNESCO/TNC) hierarchical classification. This is the basis for the classification that the Federal Geographic Data Committee (FGDC) Vegetation Subcommittee has endorsed as the standard for all Federal mapping projects. Aerial video, aerial photos, historical maps, agency records, and field reconnaissance provide ancillary data to help classify the TM imagery. Visual interpretation and computer assisted classification methodologies delineate the vegetation types. To incorporate regional vegetation differences, local abilities are matched with local interpretative needs at the State level. However, to facilitate Regional and national comparisons, individual State vegetation maps must meet these minimum standards:

- Nominal scale of 1;100,000;
- Minimum mapping unit of 100 ha, 1 square kilometer for uplands, and 40 ha for special features such as riparian areas;
- A hierarchical classification consistent with the UNESCO/TNC system; and
- Final products in ARC/INFO GIS vector format, with associated projected parameters and a data dictionary.

Table 4.4 provides cost estimates for the vegetation mapping phase of the Washington GAP. These estimates assume experienced remote sensing and GIS analysts are available so that projects are immediately operational with no time required for training.

Table 4.4. *Cost estimates for the Washington GAP.*

Time		
	Remote Sensing Analyst	3 years @ full time
	Associate Analyst	3 years @ ½ - full time
Expenses		
	Data	$100,000
	Other[1]	$200,000 - $300,000

[1] Includes but not limited to field data collection, office supplies, computer storage, travel, and publication costs.

Further information about GAP can be found on its World Wide Web site at www.gap.uidaho.edu/gap.

4.5.2 Subregion Level

Classification and Assessment With Landsat of Visible Ecological Groupings

The Classification and Assessment With Landsat of Visible Ecological Groupings (CALVEG) was developed to provide a statewide classification system and mapping effort to more adequately assess natural resources statewide (figure 4.5).

CALVEG uses a hierarchical classification that allows vegetation to be divided into broad units for Region-wide or larger landscape planning. This classification system was designed to describe existing vegetation at various levels of detail (U.S. Forest Service Regional Ecology Group, 1981).

CALVEG mapped overstory size, structure, crown closure, and plant series associations. Plant series associations were designed to collapse into lifeforms (for example, shrub, conifer, deciduous, grassland). Mapping was done using automated classification procedures based on multispectral Landsat TM imagery, field verification, aerial photography, and local knowledge from resource specialists.

CALVEG resulted in a data layer map of existing vegetation for all national forests within the Region usable for statewide forest planning. In addition, CALVEG was incorporated into a standard GIS Core Data set for every national forest in the Pacific Southwest Region. This flexible classification system permits different levels of ecological modeling, facilitates database updates, and provides the ability to correlate with national vegetation classifications.

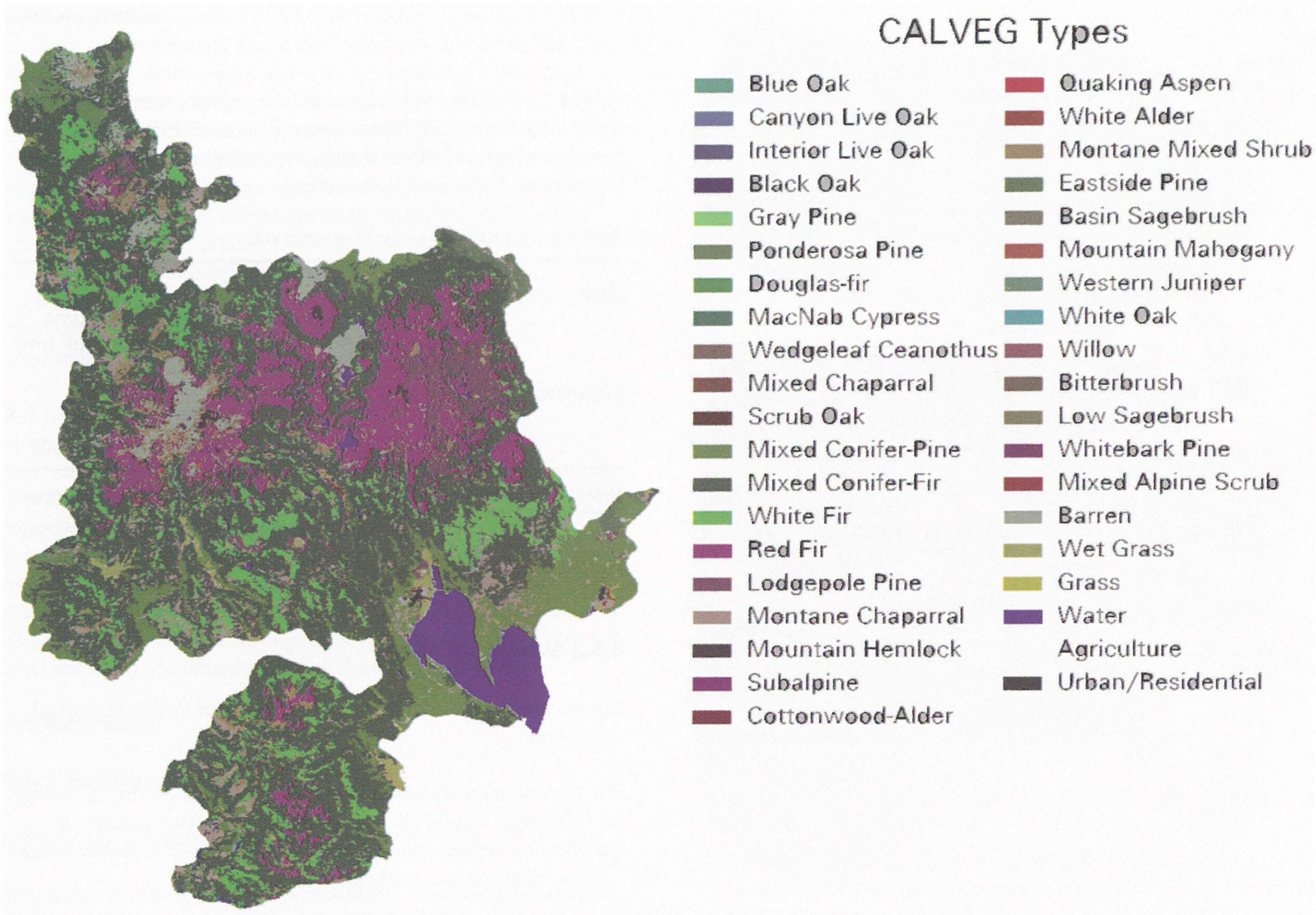

CALVEG Types
Blue Oak
Canyon Live Oak
Interior Live Oak
Black Oak
Gray Pine
Ponderosa Pine
Douglas-fir
MacNab Cypress
Wedgeleaf Ceanothus
Mixed Chaparral
Scrub Oak
Mixed Conifer-Pine
Mixed Conifer-Fir
White Fir
Red Fir
Lodgepole Pine
Montane Chaparral
Mountain Hemlock
Subalpine
Cottonwood-Alder
Quaking Aspen
White Alder
Montane Mixed Shrub
Eastside Pine
Basin Sagebrush
Mountain Mahogany
Western Juniper
White Oak
Willow
Bitterbrush
Low Sagebrush
Whitebark Pine
Mixed Alpine Scrub
Barren
Wet Grass
Grass
Water
Agriculture
Urban/Residential

Figure 4.5. *CALVEG classification scheme.*

Table 4.5 provides cost estimates for the CALVEG project. These estimates assume experienced remote sensing and GIS analysts are available so that projects are immediately operational with no time required for training.

Table 4.5. *Cost estimates for the CALVEG Project.*

Time		
	2 Remote Sensing Analysts	2 years @ full time
	2 Forestry Technicians	2 years @ full time
	1 Ecologist	2 years @ full time
Expenses		
	Data	$[1]
	Other[2]	$3,770,000[3]

[1] Data previously existed.

[2] Includes but not limited to field data collection, office supplies, computer storage, travel, and publication costs.

[3] Cost estimates based on all national forest land in Region 5 at an average cost of 16 cents/acre.

4.5.3 Landscape Level

Aspen Change Detection and Mapping for Landscape Analysis
in Southwestern Montana

The Beaverhead-Deerlodge National Forest conducted a landscape-level assessment of current and historical aspen populations. A 460,000-acre study area, located in the Gravelly Mountain Range in southern Montana, was selected to analyze current aspen locations. Remote Sensing Applications Center (RSAC) image analysts worked with Beaverhead-Deerlodge resource specialists to produce a vegetation classification based on Landsat TM using a combination of supervised and unsupervised techniques. The resource specialists interpreted the classification results by assigning labels to the 15 cover types (figure 4.6). Further refinement was necessary to account for spectral confusion between willow and aspen. Aerial photos, digital camera images, and GIS modeling using elevation and slope were employed to reduce classification errors. The 15 cover types were collapsed down to 8 because the original scheme contained more detail than could be accurately mapped within the project time frame.

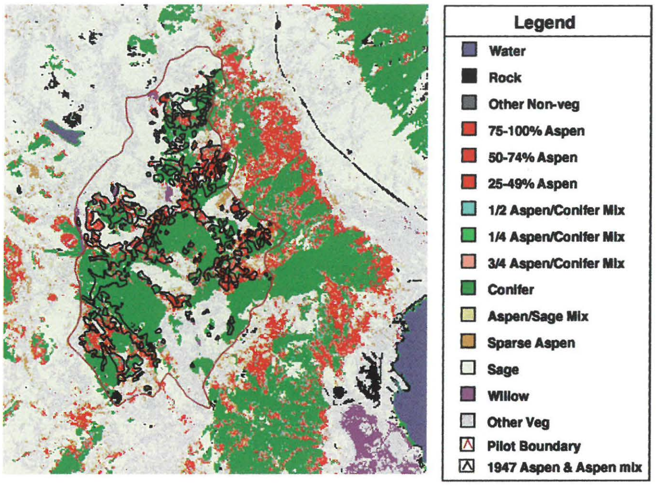

Legend
Water
Rock
Other Non-veg
75-100% Aspen
50-74% Aspen
25-49% Aspen
1/2 Aspen/Conifer Mix
1/4 Aspen/Conifer Mix
3/4 Aspen/Conifer Mix
Conifer
Aspen/Sage Mix
Sparse Aspen
Sage
Willow
Other Veg
Pilot Boundary
1947 Aspen & Aspen mix

Figure 4.6. *Aspen classification.*

To assess classification accuracy, 246 randomly selected sites across the study area were examined by photo interpreters to determine the cover type. Then photo-interpreted cover types were compared to the classified cover types. Overall classification accuracy was calculated at 69 percent. Aspen stands were mapped with 63 percent accuracy. Most errors occurred with low-density aspen stands, where the image classification overestimated the amount of aspen.

To evaluate aspen decline, historical photos were compared to the Landsat TM classification over a 6,000 acre subsection of the study area (figure 4.6). Aspen, aspen/conifer mix, and conifer cover types were interpreted from black-and-white aerial photos taken in 1947. The photo-interpreted data were then digitized and overlaid onto the satellite classification to identify changes in aspen distribution. Successional change in conifer distribution was determined to be the primary cause of aspen decline (figure 4.7).

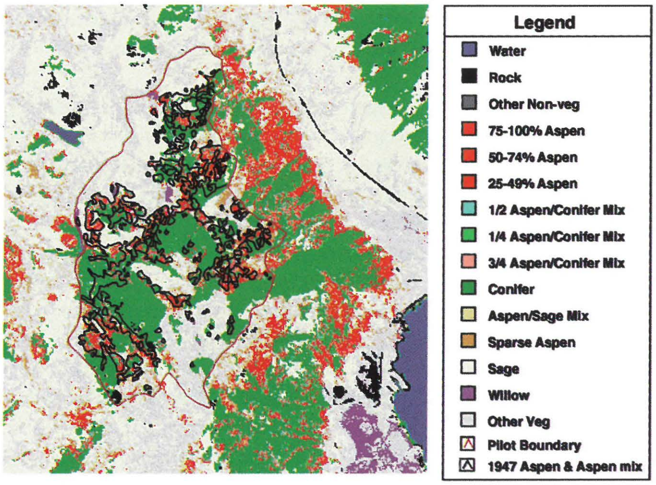

Legend
Water
Rock
Other Non-veg
75-100% Aspen
50-74% Aspen
25-49% Aspen
1/2 Aspen/Conifer Mix
1/4 Aspen/Conifer Mix
3/4 Aspen/Conifer Mix
Conifer
Aspen/Sage Mix
Sparse Aspen
Sage
Willow
Other Veg
Pilot Boundary
1947 Aspen & Aspen mix

Figure 4.7. *Aspen decline change image.*

The location and amounts of aspen decline can be estimated using historic aerial photos and recent satellite imagery. The initial classification scheme contained more detail than could be accurately mapped within the project timeframe. Because the classification is hierarchical, it was possible to collapse it. The new classification can be used to complete a digital image classification of the entire landscape unit. Researchers concluded that a less intensive, unsupervised approach with ancillary data can accurately classify mature, dense stands of aspen.

Table 4.6 provides cost estimates for the Aspen Change Detection Project. These estimates assume experienced remote sensing and GIS analysts are available so that projects are immediately operational with no time required for training.

Table 4.6. *Cost estimates for the Aspen Change Detection Project.*

Time		
	Remote Sensing Analyst	6 weeks
	Technician	4 months
Expenses		
	Data	$2,500
	Other[1]	$5,600

[1] Includes but not limited to field data collection, office supplies, computer storage, travel, and publication costs.

4.5.4 Land Unit Level

Utilization of a Supervised Landsat TM Classification for the Region 2 Integrated Resource Inventory of the National Grasslands

Analysts from the Pueblo Integrated Resource Inventory (IRI) Center, Pike and San Isabel National Forest, Region 2, used Landsat TM images to inventory unique ecosystems associated with upland grasslands. The Landsat TM classification was needed because these ecosystems were typically small areas that had been ignored by previous inventories. Classifications of the imagery were merged with GIS data to develop the Common Vegetation Unit (CVU) (figure 4.8). The GIS data base comprised hydrologic, riparian, Uresk Ecosystem Types or Natural Resources Conservation Service (NRCS) range type, fence line, and administrative boundary layers.

Training sites for the image classification were established through photo interpretation and field visits to unique sample areas. Training sites for other land cover classes (upland grass, water, and bare ground) were identified from existing field data and additional photo interpretation. A supervised classification was performed using both sets of training sites. The CVU has minimum mapping units of 5 acres for typical ground cover and 2 acres for unique cover. Nonupland grass areas (unique ecosystems) meeting these requirements were identified and added to the initial CVU as new polygons. Smaller areas were added as percentages to existing Uresk or NRCS polygons.

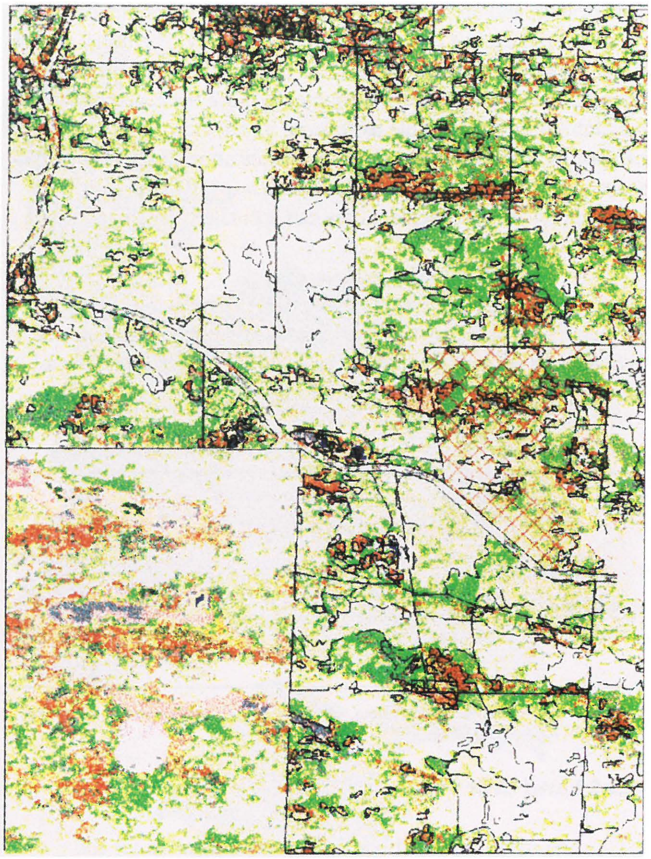


Figure 4.8. *Final CVU classification.*

Adding the classification results to the CVU data produced a data base more representative of the diverse grassland ecosystems. The Landsat TM imagery classification provided resource managers with more accurate and refined data for ecosystem management and analysis (figure 4.9).

Figure 4.9. *Field checking of TM classification.*

Table 4.7 provides cost estimates for the Landsat TM classification for the Region 2 IRI project. These estimates assume experienced remote sensing and GIS analysts are available so that projects are immediately operational with no time required for training.

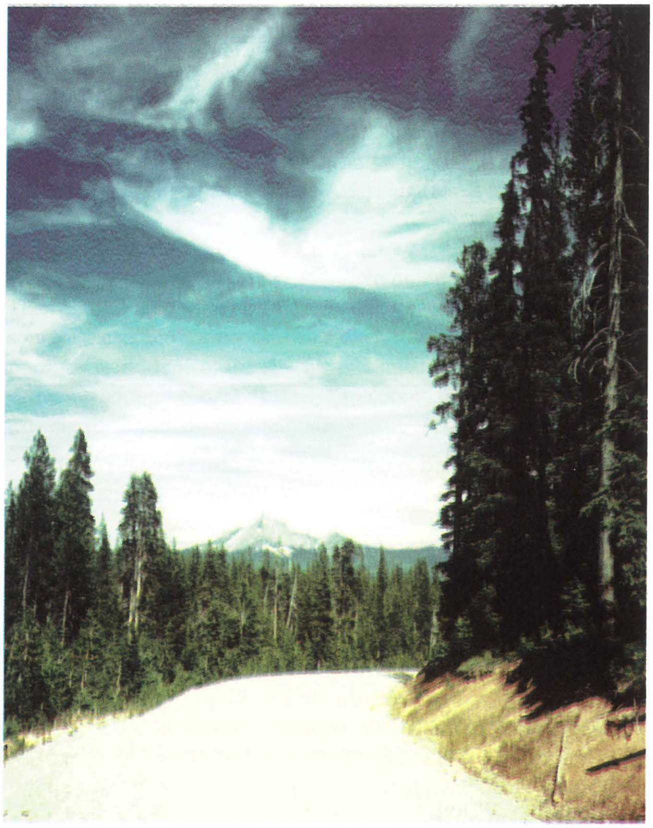
Table 4.7. *Cost estimates for the Landsat TM classification for the Region 2 IRI Project.*

Time		
	Remote Sensing Analysts	6 months @ full time
	Technician	3 months @ full time
Expenses		
	Data	7 scenes[1]
	Other[2]	$35,000

[1] Data previously existed.

[2] Includes but not limited to field data collection, office supplies, computer storage, travel, and publication costs.

5. Vegetation Attributes Derived From Remotely Sensed Data



The number and type of vegetation attributes (characteristics that define the type, extent, and size of the vegetation) that can be derived from remotely sensed data depend on the spatial and spectral resolution of the imagery used. Most attributes cannot be obtained with satellite imagery alone. Extensive field data may be necessary to help delineate particular vegetation attributes, such as, horizontal breaks. Four common attributes are canopy structure, tree size class, percent crown closure, and vegetation composition.

Deriving vegetation attributes from remotely sensed data requires field data and the incorporation of Geographic Information System (GIS) data. The field data establish a link between variation in the vegetation on the ground and spectral variation in the imagery. The training sites used in a supervised classification are selected as homogeneous representations of certain forest characteristics (in terms of canopy structure, size class, crown closure, and vegetation composition). In other instances, training sites may serve as examples of heterogeneous types, such as a mixed stand of Douglas-fir and western hemlock. The addition of information from GIS data could be used to refine both supervised and unsupervised classification results. For example, a Digital Elevation Model (DEM) is often employed to restrict certain tree species to their normal elevation range. Vector layers are often used to partition the remotely sensed data into distinct physiographic regions, thereby reducing errors caused by nonspectral variations. Aerial photos and other remote sensing imagery are normally used to label unsupervised classification cluster classes. Once the classification is complete, it becomes an additional data layer in the GIS Core Data.

5.1 Canopy Structure

Canopy structure describes the vertical structure of the vegetation-single-story or multistory. The vegetation of a single-story canopy is generally a uniform height, whereas a multistory canopy has overstory and understory components. A single-story canopy looks smooth and will have a velvet texture on remotely sensed data, but a multistory canopy has an irregular appearance.

When collecting field data, aerial photographs should be used to aid field personnel with relating ground conditions to conditions visible on satellite remotely sensed data. The presence or absence of an understory component should be recorded. These data and other data concerning the other vegetation attributes would describe the training sites used as part of the image classification process. Additionally, GIS Core Data might be used to further stratify the training sites.

5.2 Tree Size Class

Tree size class is defined by the diameter of the trees that constitute the dominant or overstory canopy. Typically, the diameters are grouped into size classes such as seedling, sapling, pole, sawtimber, and so on. Table 5.1 lists the tree size classes inventoried by each Forest Service Region. These size classes are used for ground measurements. Obtaining this level of detail with remotely sensed data is not possible. Tree size classes derived from remotely sensed data are broader and require the incorporation of field data and GIS Core Data.

This attribute requires substantially more field data than the other attributes because of the complex relation between canopy reflectance and size class. The field data necessary to derive this attribute would include sampling of the diameters of the trees in the canopy. These diameters would be grouped into size classes that are dependent on the classification scheme. Stand age obtained from GIS Core Data would help identify classification errors (for example, a typical 10-year-old pine stand would not fall into the medium sawtimber category).

5.3 Percent Crown Closure

Percent crown closure refers to the area covered by the vegetation canopy. Determining the percent crown closure is complicated in multistory forest canopies because of shadows. In addition, low crown closures (less than 15 percent) are hard to estimate because of spectral confusion with bare ground.

Percent crown closure is best estimated with aerial photographs or remote sensing imagery. Ground-based estimates are often skewed because of the inability to get a synoptic view of the stand's entire crown closure. However, this does not mean percent crown closure estimates should not be made without ground validation. Often a

Table 5.1. *Tree size classes by Forest Service region (inches).*

				Sawtimber			
FS Region	**Seedling**	**Sapling**	**Pole**	**Small**	**Medium**	**Large**	**Giant**
1	0.0 - 1.0"	1.0 - 4.9"	5.0 - 8.9"	≥9.0"			
2	0.0 - 0.9"	1.0 - 4.9"	5.0 - 8.9"	9.0 - 15.9"	≥16.0"		
3	< 1.0"	1.0 - 4.9"	5.0 - 8.9"	≥9.0"			
4	0.1 - 4.9"	0.1 - 4.9"	5.0 - 7.9"	≥8.0"			
5	< 1.0"	1.0 - 4.9"	5.0"	≥5.0"			
6	0.0 - 5.0"	0.0 - 5.0"	5.0 - 10.0"	10.0 - 20.0"	20.0 - 30.0"	30.0 - 50.0"	50.0"+
8	***only***	***record***	***raw***	***data***			
9	< 1.0"	1.0 - 4.9"	5.0 - 8.9"	≥9.0"			
10	< 4.9"	4.9"	4.9 - 8.9"	≥9.0"			

remote sensing analyst gathering field data will estimate percent crown closure before entering the training site by examining the site in stereo using aerial photographs. After visiting the training site, actual crown closure estimates are adjusted to account for canopy shadows and other conditions not apparent on the aerial photographs.

5.4 Vegetation Composition

Species groups or associations are used to define the vegetation composition attribute. The level of detail possible in determining vegetation composition is highly correlated to the spatial and spectral resolution of the remotely sensed imagery. Low spatial resolution data such as Advanced Very High Resolution Radiometer (AVHRR) can be used to identify very broad species groups (see section 4.6.1, "Resource Planning Act Forest Type Group Mapping" for an example of AVHHR derived vegetation attributes). Landsat Thematic Mapper (TM) and aerial photos can supply more detailed species groups.

Recently, the Federal Geographic Data Committee (FGDC) approved a classification system to support the production of uniform statistics on vegetation resources at the national level. These standards include principles, definitions of important terminology, and the National Vegetation Classification System (NVCS). The NVCS is a hierarchical classification system based on existing vegetation (examples are found in appendix D). The United Nations Educational, Scientific, and Cultural Organization (UNESCO) originally developed this system in the early 1970's and The Nature Conservancy (TNC) recently modified it for conservation planning.

The Forest Service was involved in the modification and approval of the NVCS and chaired the FGDC Vegetation Subcommittee. Several Federal agencies are employing the NVCS for resource inventory, management, monitoring, and conservation. These activities include the following:

- The Gap Analysis Program is mapping vegetation at the State level using Landsat TM imagery and the NVCS.
- The U.S. Fish and Wildlife Service is testing the NVCS in a pilot project and hopes to classify the entire National Wildlife Refuge System.
- The National Park Service Vegetation Mapping Program is currently under way in all national parks and is based on the NVCS.
- The Forest Service used the NVCS for the ecological assessment of the Pacific Northwest Region Columbia River Basin.

The upper levels of the NVCS are based primarily on the vegetation physiognomy of the dominant or uppermost stratum. These attributes can be determined using satellite imagery, aerial photography, and ecological modeling with GIS Core Data. The lower levels are based on floristic composition and must be classified using field data.

6. Image Processing Guidelines

The guidelines discussed here are only a brief overview of the processes involved in the analysis of remotely sensed data. A detailed, step-by-step list of procedures is impossible due to the variability of the data, as well as differences in analyst experience, classification schemes, and objectives. More detailed discussion of all the information in this chapter can be found in *Guidelines for the Use of Digital Imagery for Vegetation Mapping* (Maus *et al.*, 1995).

6.1 Data Acquisition

The best way to decide whether satellite imagery (or any other data source) meets project needs is to gather as much information about previous work done in the specific or similar areas. However, before gathering additional data, it is wise to complete an inventory of existing data sources; they may suit the needs of the project. Table 6.1 lists the steps to take before using satellite imagery in a mapping project.

Table 6.1. *Steps taken before using satellite imagery in a mapping project.*

Step 1	Define the classification scheme. The information needs of the mapping project should drive the decision to use a particular technology and scale.
Step 2	Do a literature search for similar projects completed in your geographic area or elsewhere.
Step 3	Scrutinize results (accuracy assessments) of past projects. Take a close look at individual class accuracy as opposed to overall accuracy.
Step 4	Consult experts in Regional geometronics offices and technical centers such as the Remote Sensing Applications Center.
Step 5	Become familiar with the best and worst possible scenarios and aim for something in the middle to formulate realistic goals.

In addition to the steps in table 6.1, a pilot project is an excellent means of testing the technology as well as developing methodology. Completing a pilot project is highly recommended when the team is unfamiliar with digital imagery. Taking a project from start to finish will answer unanticipated questions and bring project expectations in line with reality.

6.2 Defining the Classification Scheme

Careful planning of the classification scheme is necessary to establish an adequate foundation for a mapping project using digital imagery and GIS technologies. When a new classification is designed, it is often project specific and must attempt to balance the ideal level of detail with the limits of the project. Steps for negotiating this balance are outlined in table 6.2.

Table 6.2. *Steps in designing a classification scheme.*

Step 1	Define the user needs. The ideal level of detail and the intended use of the data must be clearly defined. Consider general data needs in addition to project-specific ones.
Step 2	Identify available resources. Consider personnel, time, budget, existing data, and management approval as the critical resources. Identify limiting factors because they often constrain the choice of a classification scheme.
Step 3	Define the technology to be used. Use the minimum resolution data necessary to meet goals.
Step 4	Reanalyze the user's needs. When mismatches between the desired and actual levels are perceived, the initial data needs should be reexamined and prioritized.
Step 5	Design a classification system. Include a cross-reference to the National Vegetation Classification System (NVCS) if necessary.

A map or Geographic Information System (GIS) layer with a well-designed classification can meet the needs of numerous users. At a minimum, a well-designed classification must possess these characteristics:

- ***Be exhaustive.*** All possible conditions must be assigned to a class, so consider the full range possibilities in or near the project area.
- ***Be mutually exclusive.*** Any vegetation condition must be assignable to one and only one class.
- ***Be flexible.*** A flexible classification allows the production of many different specialty maps based on the data, and it can respond to changing needs and definitions. Ways to add flexibility to a classification are discussed in table 6.3.
- ***Focus on basic vegetation characteristics.*** A flexible data base contains information that is as objective as possible. Interpretive or relative terms such as "old growth" or "preferred habitat" should be avoided.
- ***Define classes based on what the sensor measures.*** A classification should be defined with the aerial perspective of the remote sensor in mind.
- ***Focus on land cover, not land use.*** When using satellite imagery, be wary of mixing land cover and land use in the same classification. A satellite image provides a picture based on land cover reflectance values that can be classified. Land use must be interpreted.
- ***Compartmentalize for higher accuracy.*** Use a multi-layer approach to exploit strengths and work around the weaknesses of imagery. Classified layers, such as crown closure, size class, and species, should be individually assessed for accuracy.
- ***Use a hierarchical scheme.*** Sometimes an accuracy assessment shows that the classification has not successfully separated all classes. If this is the case, the hierarchical scheme can be collapsed to the next layer for a more general analysis, such as a regional analysis.
- ***Define classes that are discernible from photo interpretations and fieldwork.*** One test of a robust classification is that groups that can be separated on the imagery are also distinct in the ancillary data (usually aerial photos and field visits).

Table 6.3. *Ways to add flexibility to a classification scheme.*

- **A hierarchical classification scheme begins at a general level and divides each class into more detailed subclasses at the next lower level. Such a structure is flexible and easily lends itself to grouping the data into more general categories.**
- **A multilayered classification is broken down into components so that each layer can be treated separately during the image analysis phase of a project. Multilayered classifications are well suited for GIS models where, for example, tree size might be needed as an input to a habitat suitability model, but species and crown closure can be ignored.**

6.3 Reference Data Collection

Field data collection is the process of obtaining quantitative or qualitative information about ground features. Although field data collection is not always necessary, there must be some type of reference data to help interpret imagery or assess accuracy during a mapping project. In remote sensing projects, reference data serve two main purposes. First, they establish a link between variation on the ground and in the image. This link is necessary for assigning image pixels to discrete land cover types in the classification process. Secondly, reference data help assess the accuracy of a map. For most projects, the same type of data is collected for training and accuracy sites. The two functions of reference data are discussed here:

- Training sites are representative areas of land cover that are identified on both the satellite image and the ground (or appropriate reference source). In effect, training sites "train" the computer to assign information to a particular cluster of pixels during image classification.
- Accuracy assessment sites are also samples of land cover and vegetation identified on both the satellite image and the ground (or appropriate reference source), but are used after the classification is completed to quantify the accuracy of the final map.

Reference data should be recorded and organized with a data collection form, sometimes called a field form. This form should be designed after the classification scheme has been defined. The goal is to create a form that compiles a comprehensive record of information about the land cover and vegetation but is flexible enough to allow multiple interpretations. The form can be used to collect both training and accuracy data, and both can be collected at the same time.

In the best circumstances, reference data are collected on the ground. Before fieldwork can be conducted, training and accuracy assessment sites must be identified. A further discussion of training site size is found in Remote Sensing Digital Image Analysis: An Introduction (Richards, 1993). Aerial photographs are very useful for locating sites. Hints for locating training sites are listed in table 6.4. The number of training sites needed for a classification depends upon several variables. The user should review the classification scheme and then attempt to determine the potential causes of spectral variation within any given class. When slope, aspect, plant vigor, vegetation density, and other factors may affect reflectance, multiple training sites per class are recommended. Note that there is usually a point when additional training sites will not result in a better classification or at least do not warrant the additional cost and time.

Table 6.4. *Hints for locating training sites.*

- **Make sure a training site is homogeneous in vegetation/land cover attributes, such as percent canopy closure and distribution of species or size classes.**
- **Delineate multiple training sites in each category of the classification scheme. Complex vegetation classes will require more sites as opposed to barren, water, and so forth.**
- **Locate training sites in accessible areas so that field time is effective.**
- **Locate training sites in groups to minimize travel time to and from the field.**
- **Make sure a training site is large enough to be seen and located on the satellite image but small enough to minimize within-site variations.**
- **Training sites need to be distributed across the image, representing the same conditions under different illumination conditions.**

Field data collection is an important part of a mapping project and also can be the most expensive. Due to high costs, careful planning for fieldwork is important. Hints for collecting field data are listed in table 6.5.

Table 6.5. *Hints for collecting field data.*

- **Evaluate existing data sources.**
- **Record general notes about the vegetation on aerial photographs, orthophotos, or maps while traveling to or from training sites. This information will be useful during the classification process.**
- **Use aerial photographs to help determine the relationship between the image and the ground.**
- **Complete photo interpretation and reference form information while visiting the training site on the ground.**
- **Develop a consistent labeling system for training sites and document whether they were field verified or photo interpreted.**
- **Use Global Positioning System (GPS) to determine accurate plot locations.**

6.4 Image Processing

This section introduces several image processing operations commonly performed on digital image data. It also discusses the role of the image analyst and provides a step-by-step description of one of several possible approaches to image classification. Numerous other successful approaches have been used by the Forest Service and other organizations. Examples can be found in various textbooks and conference proceedings listed in the References section of this report (see Avery and Berlin, 1992; Lillesand and Keifer, 1987; and Greer, 1996). Journals like *Photogrammetric Engineering and Remote Sensing and International Journal of Remote Sensing* are also helpful.

The goal of image processing is to create an accurate and easily interpretable map for a particular application. Although many operations are performed by a computer, successful image processing relies heavily upon the expertise of the image analyst. Basic image analyst skills are described in table 6.6.

Table 6.6. *Basic image analyst skills required for image processing.*

- Understand statistical principles underlying image classification techniques.
- Understand remote sensing technology and sensor specifications.
- Understand causes of variation in land cover.
- Understand causes of spectral variation in the imagery.
- Link the variation in vegetation and land cover with the spectral variation in the imagery.

6.4.1 Image Preprocessing

Image preprocessing is performed on raw data to increase both the accuracy and interpretability of the image prior to classification. A few examples of preprocessing steps are found in table 6.7.

Table 6.7. *Image preprocessing steps.*

- Radiometric correction adjusts for variations in the image resulting from sensor anomalies or environmental conditions such as haze.
- Geometric correction reorients the image to compensate for the Earth's rotation and for variation in the position and attitude of the satellite.
- Terrain correction adjusts the image for relief distortion with the help of digital elevation data.
- Image enhancement is sometimes used prior to classification to improve the visual interpretability. The goal is to emphasize radiometric and spectral differences.
- Feature selection is a method of reducing the amount of data in a multispectral image. Feature selection involves identifying and isolating individual raw bands containing the most useful data for the particular project (Swain and Davis, 1978).
- Data transformations in the form of principal components or tasseled cap transformations can compress information and extract the most useful data for classifications.

6.4.2 Image Classification

Image classification results in the assignment of digital image data (pixels) to categories of the project classification. Thus, a correctly classified image represents areas on the ground that share particular characteristics. There are numerous approaches to computer-aided image classification. The one described here has been used on several Forest Service projects with good results (table 6.8). A flowchart for these steps is depicted in figure 6.1.

Table 6.8. *Steps in an image classification.*

Step 1	Divide the image into ecologically distinct areas to minimize confusing discrete land cover classes that appear spectrally similar on the image.
Step 2	Identify training sites across each unit identified through prior knowledge of the vegetation types on the ground.
Step 3	Interpret training sites via field visits or aerial photographs.
Step 4	Perform a classification on each area to identify the spectral variability.
Step 5	Analyze training sites and unsupervised spectral classes using evaluation techniques (for example, signature plots and divergence matrices) to develop an optimum set of signatures.
Step 6	Perform final image classification using the statistics by combining the supervised and unsupervised classes from the cluster routine.
Step 7	Model/edit problem areas of the map to improve its accuracy. Some attributes that can be modeled include vegetation composition, size class, and crown closure.

6.5 Accuracy Assessment

Accuracy assessments are essential to all remote sensing projects. First, they enable the user to compare different classification methods. Second, they provide information about the reliability and usefulness of remotely sensed data for a particular project. Finally, and most importantly, geospatial data that is going to be used in decision making must be accurate; otherwise, it is useless or results in inaccurate information. Quantitative accuracy assessment can be time consuming and expensive, but is an integral part of any digital image classification project.

Quantitative accuracy assessment depends on reference, sometimes called ground truth, data. Reference data is known information with high accuracy (theoretically 100 percent) about a specific area on the ground (the accuracy assessment site). Accuracy assessment involves comparing of the classified data for these sites to the reference data.

The error matrix is the standard way of presenting the results of an accuracy assessment (Story and Congalton, 1986). It is a square array in which accuracy assessment sites are tallied by both their image-determined category and their actual one according to the reference data (table 6.9). The major diagonal (highlighted in table 6.9) reveals those sites where the classified and reference data agree.

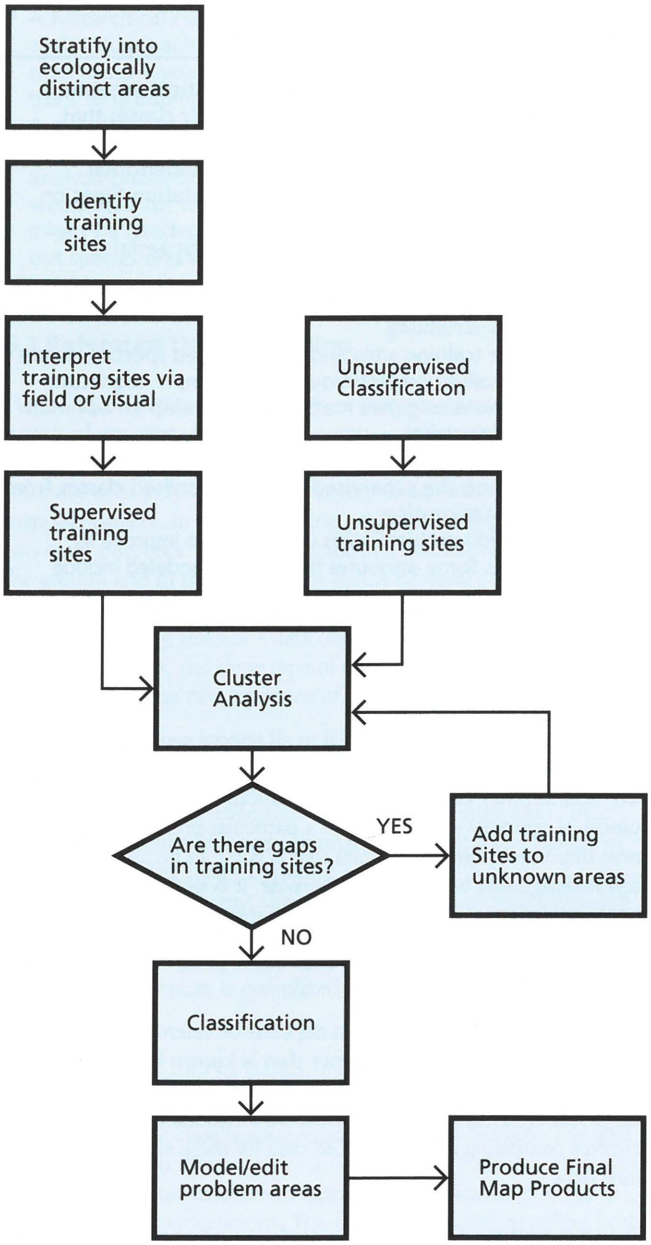

Stratify into ecologically distinct areas
Identify training sites
Interpret training sites via field or visual
Unsupervised Classification
Supervised training sites
Unsupervised training sites
Cluster Analysis
Are there gaps in training sites?
YES
Add training Sites to unknown areas
NO
Classification
Model/edit problem areas
Produce Final Map Products

Figure 6.1. *Flowchart of an example image classification routine; numerous other classification methodologies exist.*

The nature of errors in the classified map can also be detected from the matrix. In the matrix, the off-diagonal elements demonstrate either errors of inclusion (commission) or errors of exclusion (omission). High errors of omission or commission between two or more classes indicate spectral confusion.

Table 6.9. *An example of an error matrix.*

	Reference Data				
Classified Data	Deciduous	Conifer	Barren	Shrub	Row Total
Deciduous	65	4	22	24	115
Conifer	6	81	5	8	100
Barren	0	11	85	19	115
Shrub	4	7	3	90	104
Column Total	75	103	115	141	434

Overall Accuracy = 321/434 = 74%

Producer's Accuracy
Deciduous = 65/75 = 87%
Conifer = 81/103 = 79%
Barren = 85/115 = 74%
Shrub = 90/141 = 64%

User's Accuracy
Deciduous = 65/115 = 57%
Conifer = 81/100 = 81%
Barren = 85/115 = 74%
Shrub = 90/104 = 87%

Useful measures of accuracy are easily derived from the error matrix:

- Overall accuracy is computed by dividing the total correct samples (the diagonal elements) by the total number of assessment sites, found in the bottom right cell of the matrix.
- Producer's accuracy, which is based on omission error, is the probability of a reference site being correctly classified. It is calculated by dividing the total number of correct sites for a class (diagonal elements) by the total number of reference sites for that class, found in the bottom cell in each column.
- User's accuracy, which is based on commission error, is the probability that a pixel on the map actually represents that category on the ground. It is calculated by dividing the number of correct sites for a category by the total number of accuracy assessment sites in that category, found in the right-hand cell of each row (Story and Congalton, 1986).

The general steps in accuracy assessment are listed in table 6.10.

Table 6.10. *General steps in accuracy assessment.*

Step 1 Develop the sampling scheme.
Step 2 Choose the appropriate reference data.
Step 3 Delineate the accuracy assessment sites on the reference data.
Step 4 Interpret the assessment sites from the reference data.
Step 5 Compile the classified data corresponding to the reference data.
Step 6 Assess the quality of the reference data base.
Step 7 Build the error matrix.
Step 8 Summarize and present accuracy assessment results.

Accuracy assessment levels vary from project to project. They can be influenced by data resolution, classification scheme, type and accuracy of ancillary data, and analyst experience.

6.6 Polygon Creation

6.6.1 Why Produce a Polygon Classification?

One advantage of using satellite imagery is that the derived classifications may be digital and ready to be used in a GIS. Frequently, resource managers prefer a classification composed of polygons because they are more comfortable making decisions based on the familiar polygon units rather than an array of pixels. Additionally, some GIS applications and models require both the polygon and pixel format. Finally, by superimposing polygons over pixel classifications, the user can determine the amount and location of variability in each polygon. The advantages and disadvantages of representing classification results as polygons are listed in table 6.11.

Table 6.11. *Advantages and disadvantage of polygon creation.*

Advantages:

- Makes interpretation of information easier by eliminating pixel variability.
- Allows easy determination of a minimum mapping unit. Minimum polygon units are useful when, for example, a forest manager is only interested in aspen stands greater than 20 acres for input to a wildlife habitat model.
- Groups heterogeneous pixels into a homogeneous unit.
- Creates the type of map familiar to most resource managers.

Disadvantages:

- Presents a potential for losing information.
- Introduces the possibility of polygon (class) label error due to filtering (a filtered image represents a smoothing or blending of pixel data).
- Oversimplifies the way vegetation characteristics are actually related in nature.
- Slightly alters class boundaries due to filtering of the data.
- Requires additional processing and thus more cost and time.

6.6.2 Filtering

A polygon map is created from a digital classification through a technique called filtering. Filtering is a broad term that refers to the removal of spatial features for image enhancement (Jensen, 1986). The filtering process smoothes the raster data into polygon-like groups. During the process, the computer examines each pixel in relation to its neighbors. The value of the pixel being examined is changed, depending upon the type and parameters of the filter. This is done for every pixel, resulting in a new raster image.

There are many types of filters, and each has numerous options. The choice of filter, filter option, and number of filter iterations affects the appearance of the final polygons. The majority, diversity, and average filters are some of the most widely used to smooth vegetation classification results.

6.6.3 Approaches to Polygon Creation

The traditional approach to polygon creation involves classifying an image so that all vegetation characteristics are in one file. Filtering is then performed on the single-layer classification, and the file is converted to vectors.

One alternative is to use a hierarchical approach in which multiple layers (crown closure, species, and so forth) are filtered individually. Processing layers individually creates a different set of polygons for each layer. Then these layers are combined in a form that is well suited to vegetation mapping. This stratified, hierarchical process for creating polygons replicates the decisions made by photo interpreters to delineate vegetation types on aerial photos, thus producing a natural-looking classification (see Wirth *et al.*, 1994b). The basic steps for this hierarchical approach to polygon creation are found in table 6.12.

Table 6.12. *Basic steps for a hierarchical approach to polygon creation.*

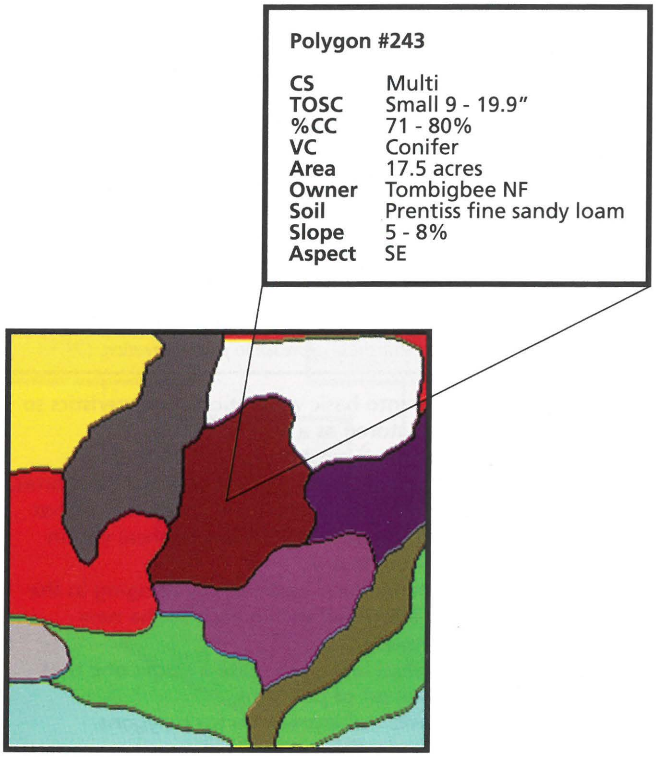
Step 1 Classify imagery into basic vegetation characteristics so that each one is stored as a separate layer.
Step 2 Filter the layer that is most important in creating polygon units and separate it into individual categories.
Step 3 Filter the next layer of vegetation characteristics (that is, the one with the next highest importance) within each category from Step 2.
Step 4 Continue this hierarchical approach by bringing in the next layer and filtering it within each of the new categories created in Step 3.
Step 5 Combine individual layers to create a single one that contains the final set of polygons.
Step 6 Convert the combined layer to vector polygons.
Step 7 Label each polygon; this is not trivial.

6.6.4 Uses of Vegetation Polygons in GIS

Vegetation polygons created by this filtering process can be used in a GIS for spatial information. These polygons can also be merged with other thematic layers, such as forest-managed stands or historical data, to provide additional information about the vegetation.

One very powerful way to use vegetation polygons is to link them back to the original classified pixels. The GIS relational data base can determine the number of pixels of each category for every polygon. The polygons can be overlaid onto the original pixels and the information about their relationship exported to a data base. For example, the percentage of different tree-size pixels that make up a given polygon can be determined. This information can then be used in a number of ways, such as labeling polygons based on the pixel distribution.

Information about differences within individual polygons can be extracted for all the pixel data including crown closure, structure, size, and species (figure 6.2). Summary tables can be created from this information and a data base designed to provide access. In this way, both the generated vector polygons in the GIS and the original classified pixel data can be used simultaneously, providing valuable information for vegetation analysis and management.



Polygon #243

CS	Multi
TOSC	Small 9 - 19.9"
%CC	71 - 80%
VC	Conifer
Area	17.5 acres
Owner	Tombigbee NF
Soil	Prentiss fine sandy loam
Slope	5 - 8%
Aspect	SE

Figure 6.2. *Example of data extraction from classification polygons.*

6.7 Project Management

Project management is the planning, organizing, and managing of resources (personnel, equipment, time, money, and data) to accomplish a defined objective (figure 6.3). Successful project management requires the following:

- A clear definition of project objectives;
- Identification of all tasks needed to reach the objectives;
- Proper allocation of resources to accomplish tasks; and
- Constant monitoring of task accomplishments and resource expenditures.

6.7.1 Project Plan

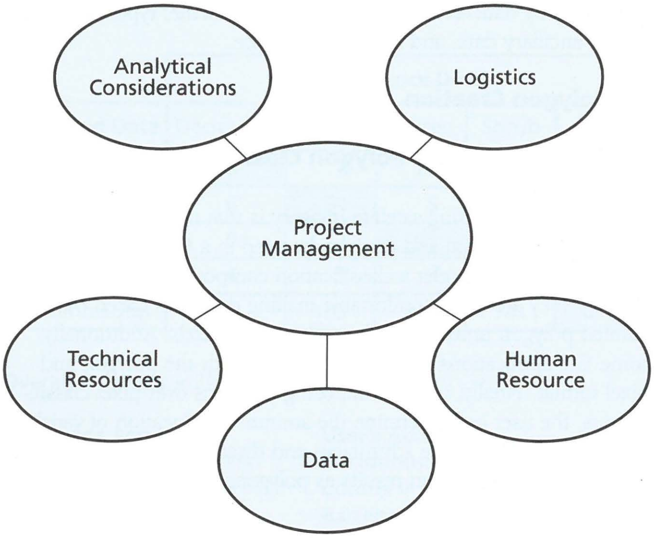


Figure 6.3. *Some important considerations that must be analyzed before undertaking a project.*

It is often said that while a perfect plan does not guarantee success, the lack of one guarantees failure. The plan must be the manager's first priority and should be maintained and updated as a written document throughout the project. At a minimum, the project plan should include four elements: an abstract or overview, a technical design, a schedule, and a budget.

The abstract should be designed for distribution to interested parties, including the public, cooperators, potential funding sources, and upper management.

The technical design should clearly and specifically accomplish the following:

- State project objectives and identify final products;
- State the methods and data sources to be used;
- Break the workload into identifiable tasks;
- Allocate hours and type of personnel by task;
- Allocate equipment (including hardware and software) by task;
- Identify material and services by task;
- Assess risk by task and provide backup plans for high-risk tasks;
- Describe the data structures, formats, and conventions to be followed; and
- Include a quality-control process.

The project schedule is constructed from the technical design in this way:

- Start with the time needed for each task as listed in the technical design.
- Determine which tasks are concurrent and which ones depend on the completion of others.
- Consider the availability of personnel.
- Consider constraints related to fieldwork, access to computers, and availability of data.
- Include time for contingency plans.
- Develop the final schedule.

The project budget is calculated by assigning costs to each task identified in the technical design. Be sure to include salaries, travel costs, equipment, material needs, and required outside services, as well as personnel time.

The project plan defines tasks and assigns resources (personnel, equipment, money, data) to those tasks. During the project monitoring phase, the manager must compare actual accomplishments and resource expenditures to planned ones. Regularly scheduled progress reports, budget reports, and daily activity logs are the main monitoring tools.

6.7.2 Budget Requirements

The widespread use and application of remote sensing in the Forest Service is evolving rapidly. As a result, it is difficult to predict budget needs for all potential projects and applications. However, several factors influence the cost of a remote sensing project, including the experience of the remote sensing analyst, computer expenses, the amount of field work required, and the level of classification and detail desired. Table 6.13 defines some costs per acre for a hypothetical remote sensing project on a forested area. General assumptions for these estimated costs include experienced remote sensing analysts, a three-element classification scheme (crown closure, tree size class, and species) with moderate detail, and several weeks of field data collection.

Table 6.13. *Cost estimates for a remote sensing project.*

Acreage	Cost/Acre
50,000 - 100,000	$0.50 - 0.60
100,000 - 200,000	$0.40 - 0.50
200,001 - 500,000	$0.30 - 0.40
500,001 - 1,000,000	$0.20 - 0.30
> 1,000,000	< $0.20

Cost-reduction methods include cost sharing with other State or Federal agencies, using a less detailed classification scheme, using local knowledge to reduce time spent in the field, and referencing previous work.

6.7.3 Time Requirements

The same variables that affect budget requirements influence the time required to complete a remote sensing project. Analyst experience and the level of detail required by the classification scheme heavily affect project length. Figure 6.4 depicts time estimates for classifying a hypothetical national forest of approximately 1 million acres.

6.7.4 Remotely Sensed Data Storage Requirements

Table 6.14 lists file sizes for the digital data most commonly available within the Forest Service for an average 7.5-minute quad. As the numbers in the table demonstrate, data resolution directly determines file size to cover a given area. As spatial resolution (pixel size) decreases and spectral resolution (number of bands, bits per pixel) increases, the file size gets dramatically larger.

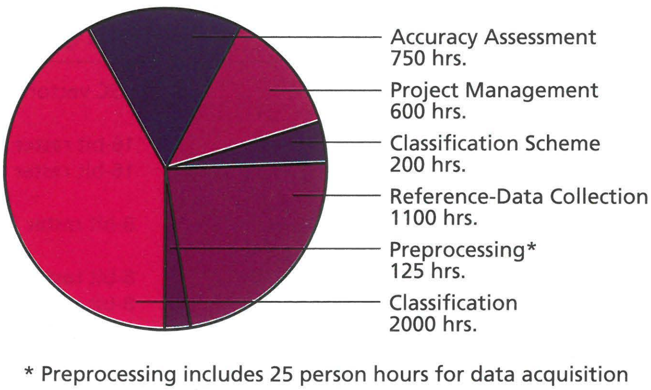


Figure 6.4. *Time estimates for a remote sensing project of a hypothetical 1-million-acre national forest. General assumptions for these estimated costs are as follows: experienced remote sensing analysts, a three-element classification scheme (crown closure, tree size class, and species groups) with moderate detail, and several weeks of field data collection.*

To efficiently analyze and manipulate these data, the computer system needs large amounts of space for intermediate, temporary, and plot files. The amount of temporary storage space needed for analysis may be 5 to 15 times the size of the data to be analyzed.

The following guidelines should be considered when determining data storage needs for projects involving digital remotely sensed data:

- Provide adequate on-line storage to complete the largest feasible project envisioned.
- Keeping the above guideline in mind, overestimate the required on-line storage space. Include provisions for multiple copies of important files, system overhead, software, and uncertainty about a particular software package's storage methods, as well as space for the project data and their analysis.
- Provide an efficient off-line storage system that allows data sets to be archived, reloaded, analyzed, and rearchived with a minimum of trouble.

6.7.5 Skills Requirements

A typical Forest Service remote sensing project involves four categories of personnel: image analyst, resource specialist, project manager, and program management. The image analyst supplies spatial data analysis skills and image processing software expertise. Resource specialists contribute expert local knowledge of ecological conditions and processes. A project manager directs, organizes, and facilitates the activities of the project team and provides computer system administrative support. Program management responsibilities include project development and funding and communication of objectives and results.

Table 6.14. *File size of various digital data for a typical USFS/USGS 7.5-minute quad.*

Data Source	Data Type	Pixel Size	File Size (Mb)
FS CFF Primary Base Layers	GSC vector format	N/A	0.8-1.20
FS/USGS DEM	16-bit raster	30 m	0.40
	16-bit raster	25 m	0.50
Landsat MSS four bands	8-bit raster	80 m	0.10
Landsat TM seven bands	8-bit raster	30 m	1.25
	8-bit raster	25 m	1.75
SPOT panchromatic one band	8-bit raster	10 m	1.60
DOQ (7.5 minute quad)	8-bit raster	1 m	272.00
Generic resource layer	4-bit raster	10 m	0.80
	4-bit raster	25 m	0.12
	8-bit raster	10 m	1.60
	8-bit raster	25 m	0.25
	16-bit raster	10 m	3.20
	16-bit raster	25 m	0.50
Scanned aerial photographs (9x9 inch photo, 1:24,000)			
Black and white, one band	8-bit raster	5 m	6.40
Color/CIR, three bands	8-bit raster	5 m	19.20
Black and white, one band	8-bit raster	2 m	40.00
Color/CIR, three bands	8-bit raster	2 m	120.00

Figure 6.5 describes the required skill level of the four personnel categories for nine skill clusters. The skill clusters are groups of remote sensing skills and knowledge necessary to complete a project. The five remote sensing skill levels are defined as follows:

Level 1: A general knowledge of the basic concepts, principles, and basic assumptions of the topic.

Level 2: A level of knowledge that permits the individual to relate the principles of the topic to specific situations.

Level 3: A level of knowledge that permits the individual to select the most appropriate imagery for a specific task, choose the processing steps that are suited to accomplishing the task, and set the parameters to perform processing.

Level 4: A level of knowledge and experience that permits the individual to apply the techniques of image analysis to a specific data set and identify the probable results.

Level 5: Sufficient knowledge of the technology, software, and underlying principles that permits the individual to apply the technology in novel ways and relate research results to current requirements (adapted from Clerke, 1990).

As indicated by figure 6.5, not all personnel are required to have an extensive background in remote sensing. Rather, a teamwork approach drawing on the strengths and knowledge of each team member is preferred.

6.7.6 Project Wrap-up

Too often, remote sensing projects are completed, published, and forgotten. This is partially the fault of project managers who failed to involve the users throughout the project or did not actively plan for the distribution and use of final results. Therefore, a primary goal of the project wrap-up is to prepare the data for future use. The manager should budget time at the beginning of the project for publications and awareness briefings and money for data distribution when the project is completed. The manager must also plan a suitable archive for the project.

Since remote sensing and GIS are relatively new technologies, others will benefit from a written postmortem of the project. This should include an overview of how the project proceeded and an indication of whether it was on schedule and within budget, and why. It should also discuss successes and failures, including descriptions of any new techniques used and advice on working around the problems encountered.

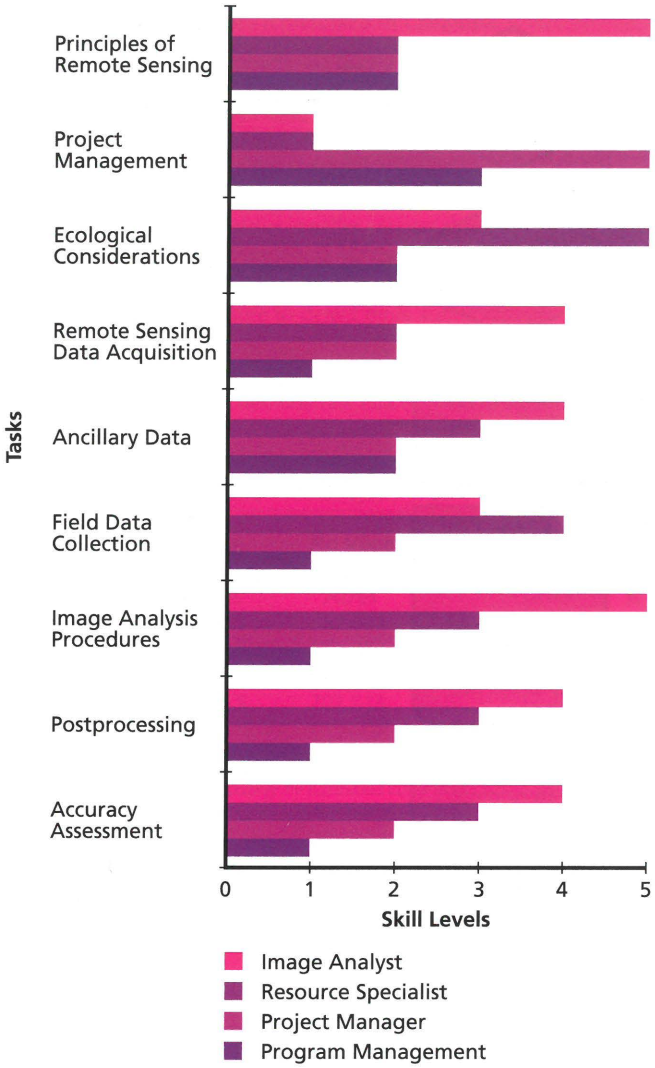


Figure 6.5. *Skill levels required by the four categories of personnel broken down by remote sensing tasks.*

7. Change Detection

7.1 Change Detection With Landsat MSS Data

Part of the Interregional Ecosystem Management Coordinating Group (IREMCG) remote sensing data procurement was the acquisition of Landsat Multispectral Scanner (MSS) triplicates. These triplicates will facilitate change detection analyses to support large area assessments and forest plan revisions. Numerous change detection methods have been developed in the past; most involve subtraction of a spectral value of one date from that of another. Both Coppin and Bauer (1994) and Green and Cosentino (1996) provide further discussion on change detection procedures.

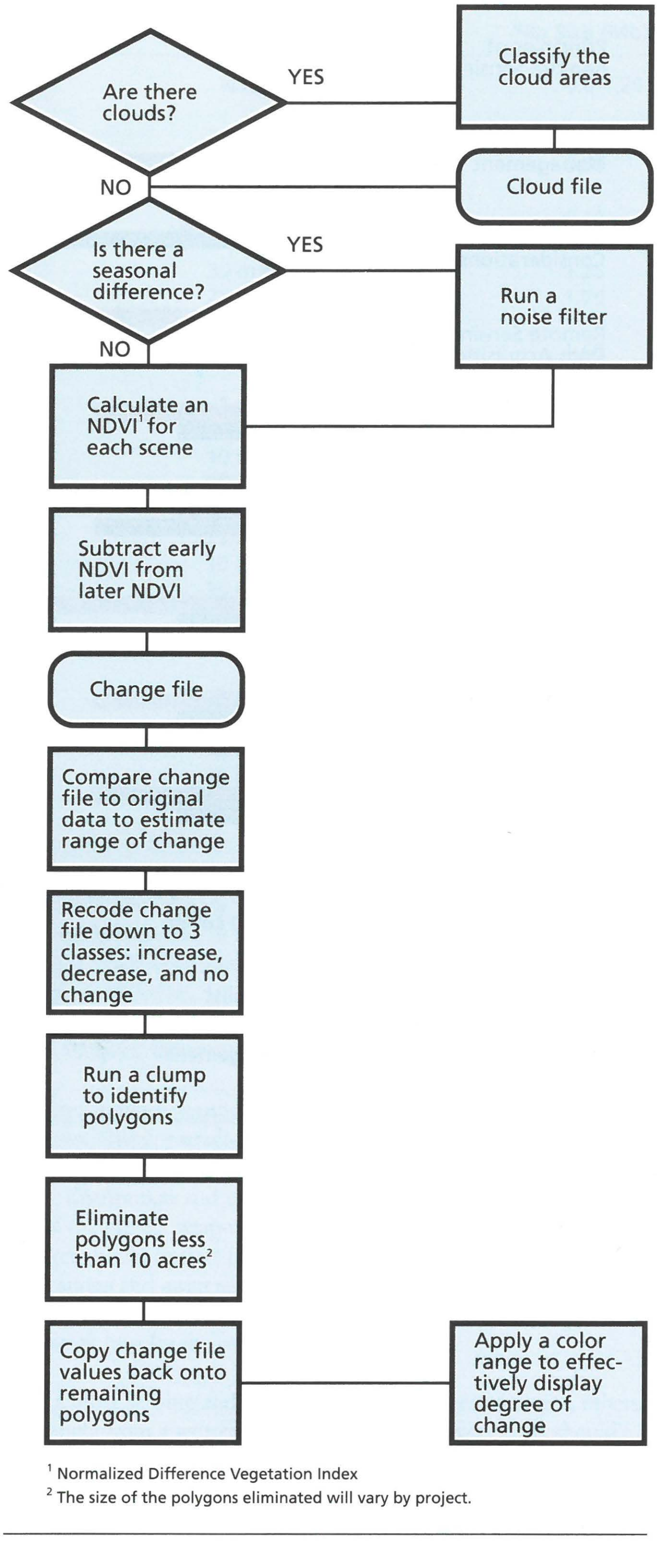
Remote Sensing Applications Center (RSAC) staff have developed an interactive procedure that allows an analyst to delineate areas of change and assign degrees of change to them (figure 7.1). Because a set of Landsat MSS triplicates are used, three change data sets are produced: change between the 1980's and 1970's, change between the 1990's and 1980's, and change between the 1990's and 1970's. The resulting data sets are useful for trend analysis, comparison of landscape changes on land with different owners, and other vegetation change detection projects. As with many other remote sensing procedures, this change detection method is not the only available option. Many other techniques and concepts have been used successfully in the past, and these should be examined for suitability within individual projects.

Some limitations in the data sets themselves affect change detection. Most of the individual triplicate data sets were acquired in the same season in each decade, but there are some exceptions. For example, the data set used by RSAC contained images from October 1972, October 1991, and July 1984. The difference in season and sun angle between the July and October images produced spots of false vegetation increase or decrease, depending on the dates compared. Clouds and cloud shadows also produced these false changes. These problems should be identified and removed from any further analysis. In addition, some areas of true change were missed because of the extended temporal difference between the images, 12 years in the 1984/1972 comparison. Despite these limitations, the procedure was deemed valid and beneficial for change detection studies.

7.2 Region 5 Change Detection Findings

The USDA Forest Service's Forest Pest Management Program (FPM) and the California Department of Forestry's (CDF) Fire and Resource Assessment Program (FRAP) and Forest Pest Management Program (CDF-FPM) are conducting a large-area change detection program using Landsat Thematic Mapper (TM) satellite imagery (Levien and Fischer, 1998). This program covers the State of California over a 5-year period beginning in 1996.

The goal of this program is to implement a long-term, low-cost and high-quality monitoring program to identify trends in forest health, assess changes in vegetation extent and composition, and provide data for updating regional vegetation and fire perimeter maps. This


Are there clouds?
YES
Classify the cloud areas
Cloud file
NO
Is there a seasonal difference?
YES
Run a noise filter
NO
Calculate an NDVI¹ for each scene
Subtract early NDVI from later NDVI
Change file
Compare change file to original data to estimate range of change
Recode change file down to 3 classes: increase, decrease, and no change
Run a clump to identify polygons
Eliminate polygons less than 10 acres²
Copy change file values back onto remaining polygons
Apply a color range to effectively display degree of change

[1] Normalized Difference Vegetation Index

[2] The size of the polygons eliminated will vary by project.

Figure 7.1. *Change detection flowchart.*

program provides current monitoring information across all ownerships and vegetation types represented in California.

Although the numbers representing acres of detected change have not been verified by an accuracy assessment, correlations do exist between detected change and various causes of change in the hardwood and conifer cover types. Large changes in vegetation cover, such as those caused from harvests and fires, are easily and most frequently detected. However, smaller canopy alterations, such as thinnings, selective harvests, brushing for defensible space, and mortality, are also detectable, demonstrating the ability of the change detection procedure to detect more subtle changes in vegetation cover.

Tables 7.1, 7.2, and 7.3 demonstrate change statistics derived from the Region 5 Change Detection program.

Table 7.1. *Acres of detected conifer change by national forest.*

National Forest	Vegetation Decrease		No Vegetation Change		Vegetation Increase	
	Acres	%	*Acres*	%	*Acres*	%
Sierra	21,268	2.3	867,694	94.8	24,557	2.7
Stanislaus	28,300	4.5	517,357	82.8	77,761	12.4
Sequoia	5,003	0.8	579,765	94.8	26,964	4.4
Inyo	3,245	0.5	702,518	97.6	13,407	1.9

Table 7.2. *Acres of detected change by hardwood cover type.*

Hardwood Cover Type	Vegetation Decrease		Vegetation Increase	
	Acres	%	*Acres*	%
Blue Oak Woodland	27,173	3.0	146,139	16.1
Blue Oak/Foothill Pine	4,957	1.8	50,521	18.1
Montane Hardwoods	31,766	4.0	104,908	13.3
Potential Hardwoods	52	4.0	101	7.8

Table 7.3. *Largest identified cause of detected change by county.*

County	Cause	Acres
Calaveras	Wildfire	5,846
Fresno	Wildfire	3,588
Kern	Harvest	405
Madera	Harvest	1,571
Mariposa	Prescribed Fire	1,884
Tulare	Wildfire	405
Tuolumne	Wildfire	4,086

The techniques employed in this project successfully demonstrate the ability to detect various levels of vegetation change in hardwood and coniferous forest environments within a 5-year time interval. Analysis of the change data provides information to assess landscape-level changes in vegetation extent and composition. It also provides information on the various causal agents (such as wildfire, harvest, and development) that are affecting the vegetation types throughout the project area.

Management applications using the change data are currently under investigation. These include vegetation map revision, fire-perimeter map updating, and timber harvesting plan (THP) evaluation. There is also work in progress to assess the effectiveness of county voluntary guidelines for oak woodland management and to estimate conifer mortality within national forests.

Continued collaboration between CDF and USDA Forest Service will analyze trends in hardwood and conifer land cover and conversion rates as each project area is revisited in the future. The collaborative nature of this project also ensures a seamless coverage of vegetation change across all administrative boundaries. Incorporating these data into current management applications facilitates an ecosystem approach to monitoring landscape changes.

8. Recommendations

Remote sensing analysis techniques, methods, and concepts vary according to data type, objectives, data acquisition date, analyst skills, and local environmental conditions. Consequently, establishing a comprehensive set of agencywide standards for all remote sensing projects at all ecological levels is impractical. These recommendations are meant to

- Facilitate data sharing;
- Eliminate duplication of effort;
- Promote technology transfer; and
- Aid ecosystem management with remote sensing technology.

8.1 Nonvegetative Land Cover Classes

Recommendation

The predicted land cover attributes listed in table 8.1 should be the framework for the consistent development of products from remotely sensed data. Portions of the USGS Land Use/Land Cover (LU/LC) Classification System should be employed to describe nonvegetative classes (Appendix D).

The USGS Land Use/Land Cover classification system was designed specifically for satellite imagery classifications (Anderson et al., 1976). The top level of the hierarchical system (Level I) is based on land cover, whereas Level II incorporates land cover and land use. The nonvegetative labels from Level I or Level II should be employed to identify features such as roads, ice fields, urban areas, and so forth. As shown in table 8.1, Level I labels should be employed with Advanced Very High Resolution Radiometer (AVHRR) classifications. Level II labels can be used with higher resolution data (that is, Landsat Multispectral Scanner (MSS), Landsat Thematic Mapper (TM), or aerial photos). Determining Level I and II labels may require ancillary data.

8.2 Vegetative Land Cover Classes

Recommendation

The predicted land cover attributes in table 8.1 should be the framework for the consistent development of products from remotely sensed data. Vegetative land cover classes may be defined by four attributes: canopy structure, tree size class, percent crown closure, and vegetation composition.

The four attributes discussed in section 5, "Vegetation Attributes Derived From Remotely Sensed Data," will be used to define vegetative land cover classes. However, not all four vegetation attributes can be derived from each remotely sensed data type as is clear in table 8.1. Individual project objective and design will determine which attributes are compiled and the level of detail. Conversely, some projects may find it necessary to gather more detailed data than the four standard vegetation attributes. In this instance a cross-reference to the recommended attributes should be part of the project design to facilitate vertical and horizontal data integration (figure 8.1 and table 8.2).

Table 8.1. *Predicted land cover attributes derived from the integration of remotely sensed data, geospatial data bases, field data collections, and ecological modeling procedures.*

					Aerial Photos		
	AVHRR	**MSS**	**TM**	**SPOT**	**Small[1]**	**Mid[2]**	**Large[3]**
Nonvegetative Land Cover Classes							
1) USGS LU/LC[4]	Anderson Level I	Anderson Level II	Anderson Level II	Anderson Level II	Anderson Level II	Anderson Level II	Anderson Level II
Vegetative Land Cover Classes							
1) CANOPY STRUCTURE	N/A	N/A	Single/ Multi	Single/ Multi	Single/ Multi	Single/ Multi	Single/ Multi
2) TREE SIZE CLASS	N/A	N/A	Generic[5,6]	Generic[6]	Generic[6]	Generic[6]	Generic[6]
3) PERCENT CROWN CLOSURE	N/A	30% Breaks[6]	10% Breaks[6]	10% Breaks[6]	20% Breaks[6]	10% Breaks	10% Breaks
4) VEGETATION COMPOSITION	NVCS Group[7,8]	NVCS Group[7]	NVCS Alliance[7,8]	NVCS Alliance[7]	NVCS Alliance[7]	NVCS Alliance[7]	NVCS Association[7]

1. Small-scale aerial photos < 1:40,000
2. Mid-scale aerial photos 1:40,000 - 1:15,000
3. Large-scale aerial photos > 1:15,000
4. USGS Land Use/Land Cover Classification System (Anderson *et al*., 1976).
5. Generic breaks 0-8.9, 9.0-19.9, 20.0+ inches.
6. May require substantial field data.
7. Requires the integration of ancillary data.
8. Appendix C lists examples of NVCS labels.

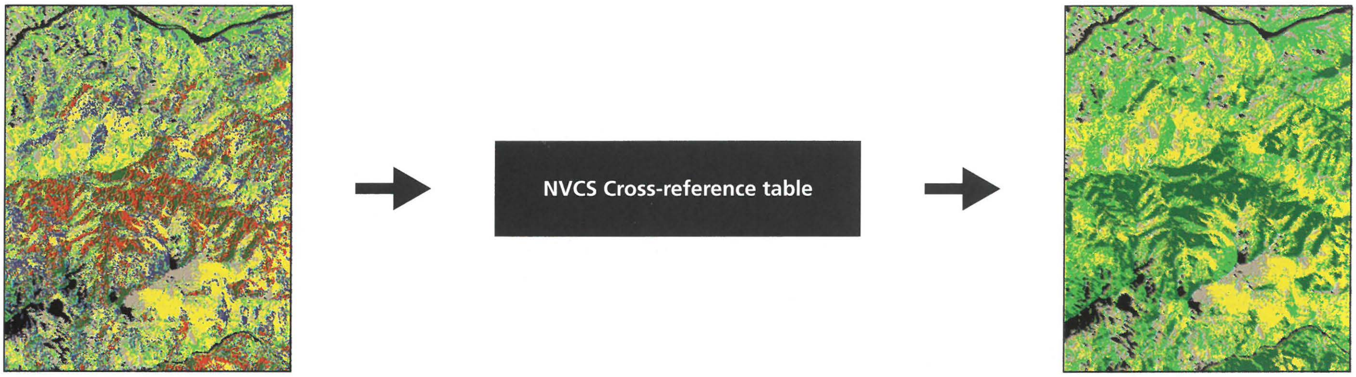


Figure 8.1. *Visual example of a cross-reference table for vegetation classes to NVCS class labels.*

Table 8.2. *Hypothetical example of a cross-reference table for vegetation classes to NVCS class labels.*

Vegetation Classes	NVCS Class Labels
Conifer (>70% canopy cover) Hardwood (>70% canopy cover)	Closed Forest (60% canopy cover)
Conifer (<70% canopy cover) Hardwood (>70% canopy cover)	Woodland (25-60% canopy cover)
Chaparral Soft Chaparral Desert Shrub Sagebrush Shrub	Scrub
Dwarf Shrub	Dwarf Shrub
Herbaceous	Herbaceous

8.2.1 Canopy Structure

Two labels, single story and multistory, will be employed to describe canopy structure. A single-story canopy is smooth textured, often a sign of a homogenous, even-aged forest. A multistory canopy has a dominant overstory and understory. This is frequently considered a multi-age forest.

8.2.2 Tree Size Class

The recommended tree size class divisions are found in table 8.3. These divisions were determined from table 5.1, Tree size classes by Forest Service region. Tree size class predictions can be improved with the incorporation of field data and Geographic Information System (GIS) Core Data.

Table 8.3. *Tree size classes as determined from remotely sensed data.*

Tree Diameter (inches)	Tree Size Class
< 8.9	Seed/Sap/Pole
9.0 - 19.9	Small
> 20.0	Medium/Large

8.2.3 Percent Crown Closure

The percent crown closure divisions vary depending on the remotely sensed data type (table 8.1). Ten-percent divisions are possible with finer spatial resolution data (for example, mid- and large-scale aerial photos, Landsat TM, and Système Pour l'Observation de la Terre (SPOT)). As with the other vegetation attributes, determining these percent crown closure divisions will require the incorporation of GIS Core Data.

8.2.4 Vegetation Composition

The National Vegetation Classification System (NVCS) as defined by the Federal Geographic Data Committee (FGDC) Vegetation Subcommittee should be used to define vegetation composition. The adoption of this system will improve horizontal and vertical data integration and promote interagency data sharing. Using the NVCS will ensure compliance with Executive Order 12906 (See section 3, "The Need for Consistent Products from Remote Sensing").

GIS Core Data will be vital to assist with NVCS class labeling. Vegetation composition attributes may be more detailed; however, a cross-reference to the NVCS is required to promote data sharing. Examples of the NVCS are listed in appendix D. A full description of the NVCS is found on the FGDC Vegetation Subcommittee web page at www.nbs.gov/fgdc.veg.

8.3 Metadata

Recommendation

Use the "Content Standard for Digital Geospatial Metadata" developed by the FGDC for documentation and archive purposes.

The FGDC has developed a common set of terminology and definitions for the documentation of digital geospatial data called "Content Standard for Digital Geospatial Metadata." Metadata are simply data about data. These are the primary functions of metadata:

- To maintain an organization's internal investment in geospatial data;
- To provide information about an organization's data holdings to catalogues, clearinghouses, and brokerages; and
- To provide information needed to process and interpret data received through a transfer from an external source (Federal Geographic Data Committee, 1997).

The metadata standard is organized in a hierarchy of data and compound elements that define the information necessary for metadata to document a set of digital geospatial data. Properly documented metadata allow a user to determine the following:

- The availability of data sets for a geographic location;
- The fitness of a data set to meet a specific need;
- How to access the desired data set; and
- How to process and use a specific data set.

The metadata standard has been adopted by numerous Federal, State, and local agencies, private companies, and other groups. This standard should be implemented to facilitate data sharing and reduce duplication of effort.

For further information on the metadata standard and other FGDC activities, visit the FGDC home page at www.fgdc.gov.

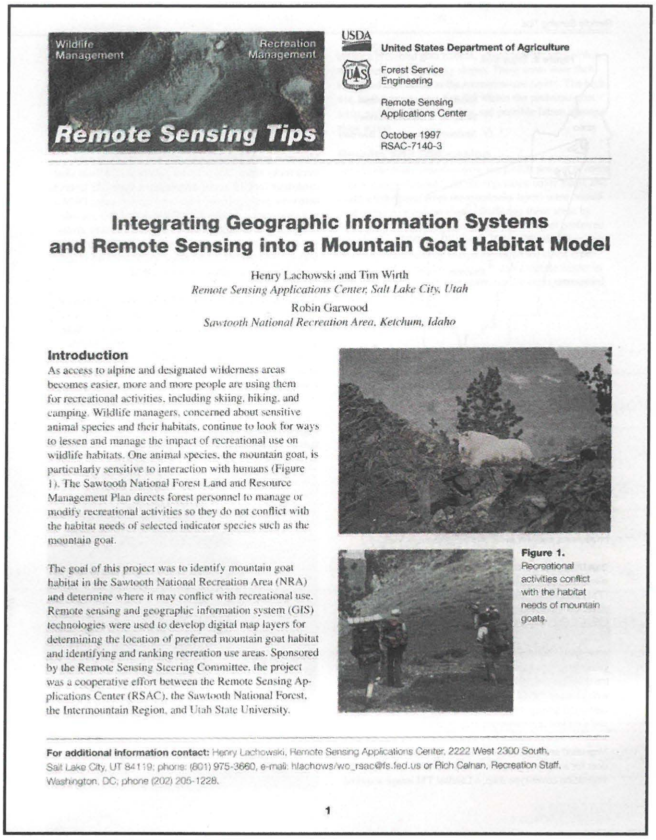
8.4 Clearinghouse

Recommendation

Establish a clearinghouse within the existing Forest Service Intranet for collection and dissemination of remote sensing data, products, and reports.

Establishment of a remote sensing clearinghouse would comply with Executive Order 12906 and tie to other clearinghouses within the agency once they are developed. A web browser could query a clearinghouse data base for existing remote sensing products. The clearinghouse would only retain the metadata and a thumbnail graphic of the image. The actual geospatial data sets or corporate data would reside on a server at the local or regional level where they were produced. Should users require the corporate digital data set, hypertext linkages would permit them to download the digital data set directly.

The clearinghouse should also include a forum for technology transfer and exchange of ideas about remote sensing. Users should be able to access project summaries, review current Forest Service remote sensing literature, and post questions or tips for other analysts. The Remote Sensing Applications Center (RSAC) has produced several short papers describing recent projects (figure 8.2). Each paper is less than four pages and includes color figures. This format is well suited for reproduction on the Forest Service Intranet.



Wildlife Management
Recreation Management
Remote Sensing Tips

USDA
United States Department of Agriculture
Forest Service
Engineering

Remote Sensing
Applications Center

October 1997
RSAC-7140-3

Integrating Geographic Information Systems and Remote Sensing into a Mountain Goat Habitat Model

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Remote Sensing Applications Center, Salt Lake City, Utah
Robin Garwood
Sawtooth National Recreation Area, Ketchum, Idaho

Introduction

As access to alpine and designated wilderness areas becomes easier, more and more people are using them for recreational activities, including skiing, hiking, and camping. Wildlife managers, concerned about sensitive animal species and their habitats, continue to look for ways to lessen and manage the impact of recreational use on wildlife habitats. One animal species, the mountain goat, is particularly sensitive to interaction with humans (Figure 1). The Sawtooth National Forest Land and Resource Management Plan directs forest personnel to manage or modify recreational activities so they do not conflict with the habitat needs of selected indicator species such as the mountain goat.

The goal of this project was to identify mountain goat habitat in the Sawtooth National Recreation Area (NRA) and determine where it may conflict with recreational use. Remote sensing and geographic information system (GIS) technologies were used to develop digital map layers for determining the location of preferred mountain goat habitat and identifying and ranking recreation use areas. Sponsored by the Remote Sensing Steering Committee, the project was a cooperative effort between the Remote Sensing Applications Center (RSAC), the Sawtooth National Forest, the Intermountain Region, and Utah State University.

Figure 1. Recreational activities conflict with the habitat needs of mountain goats.

For additional information contact: Henry Lachowski, Remote Sensing Applications Center, 2222 West 2300 South, Salt Lake City, UT 84119; phone: (801) 975-3660, e-mail: hlachows/wo_rsac@fs.fed.us or Rich Calnan, Recreation Staff, Washington, DC; phone (202) 205-1228.

1

Figure 8.2. *Remote Sensing Tips for integrating geographic information systems and remote sensing into a mountain goat habitat model.*

8.5 Training

Recommendation

A "core competency" requirement relating to remote sensing awareness and implementation should be determined for all natural resource staff and line management. Ensure, through individual development plans, that personnel receive training to meet these requirements.

Upgrades to the Forest Service IBM computer system will include image processing and GIS software. Each Region, forest, district, and research unit will have the capability to create and manipulate data sets to meet its own needs. A general understanding and appreciation of digital remotely sensed data, analysis procedures, and results are necessary for effective internal and external communication. Requirements and training to meet those core competencies will differ for each employee. The general level of competency

required is one that permits communication and understanding among various staff about projects in which they are involved. Resource specialists need not be experts in remote sensing, although they should be able to understand basic concepts, terminology, and application. Forest Supervisor offices need to have enough staff expertise to specify and obtain the remote sensing services they require to manage resources at the national forest level.

> ***Recommendation***
> Develop a training program to meet the skill requirements of designated image analysts and GIS Core Data technical staff at the national forest level. Identify opportunities for background strengthening and skills improvement, and ensure that critical personnel receive training to meet identified requirements.

The Forest Service IBM system will provide GIS and image processing tools to support ecosystem management. However, appropriately skilled image analysts and GIS Core Data technicians are in short supply, especially at the forest and district level. Remote sensing cannot be learned simply by reading a manual and following a software tutorial. Skilled remote sensing support personnel must be familiar with remote sensing principles, aerial photo interpretation, database management, spatial modeling, and GIS analysis and have an understanding of ecological processes. A consistent Service-wide training program is required to develop the technical skills necessary to incorporate remote sensing for ecosystem management throughout the Forest Service.

Many remote sensing, modeling, monitoring, and resource survey and analysis training opportunities are available within the Forest Service. Some are offered at Regional and forest levels, while others take place at the national level. Many of these are listed in the Forest Service Corporate Training Office (CTO) National Training Catalog. The CTO coordinates the training courses it lists, while the actual instruction is provided by specialists in the subject areas. RSAC also offers specialized remote sensing training courses (figure 8.3). The eight courses in table 8.4 were offered by RSAC in 1997. Arrangements for training should be coordinated through Regional Geometronics Coordinators. Additional remote sensing training and technical support projects can be arranged through the Regional Geometronics Coordinators and RSAC. See appendix H for a list of Geometronics Coordinators.

Figure 8.3. *The Training and Technical Awareness program at RSAC teaches several aerial photography and digital image processing classes each year.*

Table 8.4. *Aerial photo and remote sensing courses currently offered by RSAC.*

Integrating Remote Sensing and GIS
Basic concepts and processes to integrate remote sensing with GIS for resource applications emphasizing ecosystem management applications.

Basic Aerial Photo Use
Learn how to use existing aerial photos and prepare interpreted data for input to GIS. Includes principles of photo interpretation, photogrammetry, orienteering, cartography, and mapping.

Advanced Aerial Photo Use
A variety of courses are available for aerial photo users, including Non-standard Formats, Project Specific Photo Acquisition and Flight Planning, and Forest Health Protection Applications.

Aerial Videography and Digital Camera Imagery for Resource Applications
The basics needed to apply these technologies to resource applications. Covers quipment usage, Charged Coupled Device (CCD) sensor and signal characteristics, video formats, resolution, natural color and color infrared (CIR) interpretation, camera (image) geometry, flight planning, and image analysis.

Digital Image Processing
The basics of digital image processing applied to satellite-acquired information for field, technical, project manager, and GIS staff involved in resource data collection, database development, information display, and special-purpose mapping.

Global Positioning Systems (GPS) Applications
Basic concepts and techniques for collecting spatial and attribute data on ground features using state-of-the-art satellite geopositioning technology. The course stresses project planning and differential data correction methodologies.

Cartography for GIS Users
Basic cartographic skills for all GIS users, providing instruction in essential principles, skills, and tools of cartography. This course was developed jointly by the Geometronics Service Center (GSC) and RSAC.

Photography for Cultural Resources Management Applications
Covers a variety of photography acquisition, analysis, and derived product applications to cultural resources management needs, including aerial and ground photos and several other kinds of imagery.

Opportunities for training outside the Forest Service, such as classes at universities, conference workshops, interagency training, or sessions at private corporations, should be explored. Many colleges and universities have developed GIS and remote sensing programs within their natural resource departments. These programs teach relationships between GIS data bases and academic fields of study such as forestry, rangeland management, wildlife ecology, and fisheries.

8.6 Technical Support

Recommendation
Establish a help desk (intranet and telephone-based) to supply technical and user application support for the Forest Service image processing technology.

Technical support must be provided to use remote sensing and related geospatial technologies effectively within the Forest Service. The help desk would provide not only software technical assistance, but also assistance with image processing techniques and integration of remotely sensed data with other geospatial data layers. It will be a valuable resource for beginning image analysts and provide support for continued professional development.

The intranet-based help desk will provide a forum for disseminating information on current remote sensing activities within the Forest Service. Additionally, users will be able to find quick solutions to geospatial analysis problems for ecosystem management.

9. Literature Cited

Anderson, J.R., Hardy, E.E., Roach, J.T., and Witmer, W.E. (1976). *A land use and land cover classification system for use with remote sensor data* (USGS Professional Paper 964). Reston, VA: U.S. Geological Survey.

Avers, P.E., Cleland, D.T., McNab, W.H., Jensen, M.E., Bailey, R.G., King, T., and Goudey, C.B. (1993). *National hierarchical framework of ecosystem units.* Washington, DC: USDA Forest Service.

Avery, T.E., and Berlin, G.L. (1992). *Fundamentals of remote sensing and airphoto interpretation* (5th ed.). New York: Macmillan Publishing Company.

Bailey, R.G. (1996). *Ecosystem geography.* New York: Springer-Verlag.

Bobbe, T. J., Zigadlo, J.P. (1995). Color Infrared Digital Camera System Used for Natural Resource Aerial Surveys, *Earth Observatory - Magazine*, pp. 60-62.

Clerke, B. (1990). *The Forest Service remote sensing skill matrix.* Unpublished report.

Coppin, P.R., and Bauer, M.E. (1994). Processing of multitemporal Landsat TM imagery to optimize extraction of forest cover change features. *IEEE Transactions on Geoscience and Remote Sensing,* 32(4), 918-927.

Federal Geographic Data Committee. (1997). *Content standard for digital geospatial data.* Washington, DC.

Green, K., and Cosentino, B. (1996, February). Using satellite imagery to detect and monitor forest change. *Geo Info Systems*, pp. 22-30.

Greer, J.D. (ed.). (1996). Remote Sensing: *People in Partnership with Technology. Proceedings of the Sixth Forest Service Remote Sensing Applications Conference* 448 p. Bethesda, MD: American Society for Photogrammetry and Remote Sensing.

Jensen, J.R. (1986). *Introductory digital image processing: A remote sensing perspective*. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Levien, L., and Fischer, C. (1998). Unpublished report.

Lillesand, T.M., and Kiefer, R.W. (1987). *Remote sensing and image interpretation* (2nd ed.). New York: John Wiley & Sons.

Maus, P., Lachowski, H., Golden, M., Johnson, J., Landrum, V., Powell, J., Varner, V., Wirth, T., Gonzales, J., and Bain, S. (1995). *Guidelines for the use of digital imagery for vegetation mapping.* Washington, D.C: USDA Forest Service.

Myhre, R., and Silvey, B. (1992). An airborne video system developed within forest pest management status and activities. In *Proceedings of the Fourth Forest Service Remote Sensing Applications Conference*. Pp. 291-300. Orlando, FL: American Society for Photogrammetry and Remote Sensing.

Powell, D.S., Faulkner, J.L., Darr, D.R., Zhu, Z., and MacCleery, D.W. (1993). *Forest resources of the United States*, 1992 (General Technical Report RM-234). Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station.

Richard, J.A. (1993). *Remote sensing digital image analysis: An introduction*. New York: Springer Verlag.

Stoms, D., Davis, F., Cogan, C., and Cassidy, K. (1994). *Assessing land cover map accuracy for GAP analysis* [on-line]. Available: www.gap.uidaho.edu/gap/Publications/Publications.htm

Story, M., and Congalton, R.G. (1986). Accuracy assessment: A user's perspective. *Photogrammetric Engineering and Remote Sensing*, 52(3), 397-399.

Swain, P.H., and Davis, S.M. (1978). *Remote sensing: The quantitative approach*. New York: McGraw Hill.

U.S. Forest Service Regional Ecology Group. (1981). *CALVEG: A classification of California vegetation*. San Francisco: USDA Forest Service, Region Five.

Warbington, R., Askevold, R., and Simmons, W. (1993). Building a regional GIS planning database for the national forests of California. *The Compiler*, 11(4), 43-45.

Wirth, T., Maus, P., Lachowski, H., Taylor, J., and Lindquist, E. (1994a). *Investigative report on digital orthophoto quadrangles using data from the Superior National Forest*. Unpublished report.

Wirth, T., Vosburgh, J., Morton, A., and Green, K. (1994b). The integration of raster and vector data for natural resource management. *In Proceedings of the Fifth Biennial Forest Service Conference on Remote Sensing* pp. 58-71. Portland, OR: American Society for Photogrammetry and Remote Sensing.

Zhu, Z. (1994). *Forest density mapping in the lower 48 states: A regression procedure* (Research Paper SO-280). New Orleans: USDA Forest Service, Southern Forest Experiment Station.

Zhu, Z., and Evans, D.L. (1994). U.S. forest types and predicted percent forest cover from AVHRR data. *Photogrammetric Engineering and Remote Sensing*, 60(5), 525-531.

10. Appendices

Appendix A

Remote Sensing Data Sources

Remotely sensed data comes from a variety of sources, including multispectral sensors, radar systems, and aerial photographs. Digital remotely sensed data have four defining characteristics: spectral resolution, spatial resolution, temporal resolution, and swath width. Spectral resolution describes the part of the electromagnetic spectrum that is sensed. Spatial resolution is the amount of area covered by each picture element (pixel) of the data. The length of time between observations of a location is called temporal resolution. Swath width is the area covered by a single overpass of the sensor.

This appendix describes common sources of remotely sensed data. This list is not meant to be all-inclusive, since new sensors are coming on-line each year.

Advanced Very High Resolution Radiometer (AVHRR)

The AVHRR sensor has been collecting data since the late 1970's. Imagery is available on a daily basis as individual scenes or as a biweekly composite of relatively cloud-free to cloud-free scenes for the entire United States. Applications of AVHRR data include mapping past and present stream channels, measuring surface water temperatures, mapping snow cover, monitoring floods, analyzing regional soil moisture, mapping wild fire fuel, detecting fires, monitoring dust and sand storms, mapping regional drainage and physiographic features, and monitoring volcanic eruptions. The 1993 RPA assessment map used biweekly composites of AVHRR data to map forest type groups for the entire United States (Zhu and Evans, 1994).

Band	Spectral Resolution (μm)	Spectral Location
1	0.58 - 0.68	Red
2	0.72 - 1.10	Near IR
3	3.55 - 3.93	Thermal IR
4	10.3 - 11.3	Thermal IR
5	11.5 - 12.5	Thermal IR

- Spatial Resolution: 1.1 km
- Temporal Resolution: Daily
- Swath: 2,400 km

Multispectral Scanner (MSS)

The MSS sensor was launched aboard Landsat 1 (originally named ERTS-1) on July 23, 1972. It is a four-band multispectral scanner, with two visible bands and two reflected infrared ones. The MSS data have been used for land cover classification, change detection, geological investigation, geomorphological mapping, hydrological studies, forest inventory, soil studies, oceanography, and crop yield estimations.

Band	Spectral Resolution (μm)	Spectral Location
1	0.5 - 0.6	Green
2	0.6 - 0.7	Red
3	0.7 - 0.8	Near IR
4	0.8 - 1.1	Near IR

- Spatial Resolution: 80 m
- Temporal Resolution: 16 days
- Swath: 185 km

Landsat Thematic Mapper (TM)

The TM sensor has been carried aboard Landsat-4 and -5. Data are collected in seven electromagnetic spectral bands that were selected for vegetation analysis. TM data have been widely used in resource management fields, including agriculture, cartography, civil engineering, forestry, geology, geography, and land resource and water resource analysis. Landsat-4 and -5 are beyond their expected service life but are still acquiring useful data. Landsat-6 failed to achieve orbit. Landsat-7 is planned for launch in December 1998.

Band	Spectral Resolution (μm)	Spectral Location
1	0.45 - 0.52	Blue
2	0.52 - 0.60	Green
3	0.63 - 0.69	Red
4	0.76 - 0.90	Near IR
5	1/55 - 1.75	Mid IR
6	10.4 - 12.5	Thermal IR
7	2.08 - 2.35	Mid IR

- Spatial Resolution: 30 m (Band 6 - 120m)
- Temporal Resolution: 16 days
- Swath: 185 km

Système Pour l'Observation de la Terre (SPOT)

SPOT-1 was launched in February 1986, and SPOT-4 was launched in 1998. Each SPOT satellite carries two high-resolution visible (HRV) sensors that can operate in multispectral or panchromatic mode. Applications of SPOT data have been similar to those of Landsat TM. SPOT's slightly higher spatial resolution, compared with Landsat TM, can improve detection of smaller features but reduces the swath width and increases the temporal resolution.

Multispectral

Band	Spectral Resolution (μm)	Spectral Location
1	0.50 - 0.59	Green
2	0.61 - 0.68	Red
3	0.79 - 0.89	Near IR

- Spatial Resolution: 20 m
- Temporal Resolution: 26 days
- Swath: 60 km

Panchromatic

Band	Spectral Resolution (µm)	Spectral Location
1	0.51 - 0.73	Green - Red

- Spatial Resolution: 10 m
- Temporal Resolution: 26 days
- Swath: 60 km

Indian Remote Sensing (IRS)

IRS-1C and IRS-1D were launched in 1995 and 1996 and have specific application for vegetation discrimination and land cover mapping. Three sensors are carried on board the IRS-1C and IRS-1D: the LISS (Linear Imaging Self Scanning sensor), WiFS (Wide Field Sensor), and a panchromatic sensor. The 5-meter panchromatic instrument has the highest spatial resolution of remotely sensed data commercially available at this time. The LISS sensor is comparable to the Landsat TM in spatial and spectral resolution. The WiFS data are similar to AVHRR.

LISS-III

Band	Spectral Resolution (µm)	Spectral Location
2	0.52 - 0.59	Green
3	0.62 - 0.68	Red
4	0.77 - 0.86	Near IR
5	1.55 - 1.70	Short Wave IR

- Spatial Resolution: 23 m (Band 5 - 70m)
- Temporal Resolution: 24 days
- Swath: 142 km (Band 5 -148 km)

Panchromatic

Band	Spectral Resolution (µm)	Spectral Location
1	0.50 - 0.75	Green - Red

- Spatial Resolution: 5 m
- Temporal Resolution: 24 days
- Swath: 70 km

WiFS

Band	Spectral Resolution (µm)	Spectral Location
1	0.62 - 0.68	Red
2	0.77 - 0.86	Near IR

- Spatial Resolution: 188 m
- Temporal Resolution: 5 days
- Swath: 774 km

RADARSAT

The Canadian Space Agency launched RADARSAT in 1995 to monitor environmental change and support resource sustainability. RADARSAT carries a Synthetic Aperture Radar (SAR), which is a microwave instrument capable of transmitting and receiving data through clouds, haze, smoke, and darkness. This capability makes radar data advantageous for assessing areas that are rarely cloud-free. The swath width of RADARSAT data can range from 35 kilometers (10-meter resolution) to 500 kilometers (100-meter resolution). Applications of RADARSAT and other types of radar data include monitoring sea ice for ship navigation, monitoring crops, and mapping timber and snow distribution.

Operating Mode	Incidence Angle (Deg)	Spatial Resolution (m)	Swath (km)
Standard	20 - 49	28 x 25	100
Wide Swath	20 - 39	28 x 35	150
Fine Res	37 - 48	10 x 9	45
Extended Coverage	49 - 59	20 x 28	75
ScanSAR	20 - 39	50 x 50	300
Narrow	31 - 46	50 x 50	300
Wide	20 - 49	100 x 100	500

- Temporal Resolution: 24 days

European Space Agency (ESA) Earth Resource Satellite (ERS)

ESA operates two satellites, ERS-1 and ERS-2, which carry several instruments for gathering remotely sensed data. One instrument, a SAR, produces cloud-free radar images. The other instruments collect atmospheric data. ERS data are similar to RADARSAT in that both can be used to assess and monitor vegetation.

Japanese Earth Resources Satellite (JERS)

JERS acquires data in four multispectral bands and a SAR. Bands 3 and 4 sense the same portion of the electromagnetic spectrum; however, band 4 is forward looking, thus providing stereoscopic capability. The SAR aboard JERS is slightly different from the sensors on RADARSAT and ERS. The JERS SAR operates in the L-band, while the other two operate in the C-band part of the spectrum.

Aerial Photos

An interagency program called the National High Altitude Photography (NHAP) program was established in 1980 to build a uniform archive of aerial photos of the 48 conterminous States. Black-and-white and color-infrared photos were acquired on every mission and at an approximate scale of 1:80,000 and 1:58,000, respectively. In 1987 the flight specifications were modified along with the name, NHAP became the National Aerial Photography Program (NAPP). Black-and-white and color-infrared NAPP photos have a 1:40,000 scale centered on quarters of 7.5-minute quadrangles. Strict specifications regarding Sun angle, cloud cover, haze, stereoscopic coverage, and image inspection have resulted in an archive of consistent, high-quality aerial photographs. Aerial photos are an important source of ancillary data for interpreting satellite images. Softcopy photogrammetry modules on many image processing software packages allow the user to analyze and manipulate digital copies of aerial photos.

Airborne Video

Airborne video data are acquired using conventional fixed-wing aircraft or helicopters. The video camera is mounted in a port or secured outside the aircraft. Typically, Global Positioning System (GPS) data are encoded onto the video frames. The video data can be viewed in real time, allowing the user to make any necessary adjustments during flight, a distinct advantage over aerial photos. Individual frames can be analyzed, or a digital mosaic can be constructed. Video data can be acquired at a range of scales, another characteristic that makes it well suited for ecosystem management. The Forest Health Technology Enterprise Team (FHTET) in Fort Collins, Colorado, developed a standard airborne video system for Forest Service use. The system supports Forest Health Protection aerial surveys, riparian monitoring, Geographic Information System (GIS) updates, range surveys, and other applications that require imagery within a short period of time (Myhre and Silvey, 1992).

Other Digital Data Sources

Global Positioning System (GPS)

GPS consists of two components: A constellation of 24 satellites, and ground receivers. A user operates the ground unit to receive microwaves from the satellites, which are used to calculate coordinate estimates of a particular location. GPS was developed for military purposes and is administered by the Department of Defense (DOD). Errors are introduced to the transmitted signals by DOD to prevent misuse by foreign or domestic groups. However, the error (selective availability, or SA) can be removed by placing a receiver unit over a known location (the base station) and using the mean differences between estimated and known coordinates to correct position estimates of data collected with a rover unit (the unit used to collect positions of features of interest). These coordinate data have numerous applications: Georeferencing satellite imagery, updating GIS data bases, relocating benchmarks, real-time vehicle tracking, and so forth. Many GPS units are already in operation in various segments of the Forest Service.

Digital Color-Infrared Camera

The Kodak DCS 420 Digital Color-Infrared Camera is a rugged, lightweight camera body and lens capable of producing high-resolution color-infrared digital imagery (Bobbe and Zigadlo, 1995). In addition, there is a GPS interface to georeference imagery with position data. Instead of being recorded on film, each image is stored as a compressed file on a removable hard disk called a PCMCIA card. A 340-MB PCMCIA card can store 205 images. The images can be downloaded to a computer for analysis, mosaicking, or printing. RSAC has evaluated and demonstrated the Digital Color-Infrared Camera system for a variety of resource applications, including forest pest aerial surveys, riparian monitoring and mapping, noxious weeds mapping, GIS layers updating, range monitoring, and burn area rehabilitation.

Data Products

Digital Elevation Model (DEM)

DEM data consist of an array of regularly spaced elevations. The U.S. Geological Survey (USGS) distributes DEM data in 7.5-minute, 15-minute (Alaska only), and 1-degree units. Imagery can be "draped" over DEM data to create a three-dimensional model, which is useful for determining the visual effects of forest management and has been used in watershed analysis.

Digital Line Graph (DLG)

DLG data are digital representations of cartographic information. DLG's of map features are converted to digital form from maps and related sources. USGS DLG data are classified as large, intermediate, and small scale. Large-scale DLG data are derived from 7.5-minute topographic quadrangle maps and contain nine categories: (1) hypsography, (2) hydrography, (3) vegetation surface cover, (4) nonvegetative features, (5) boundaries, (6) survey control and markers, (7) transportation, (8) manmade features, and (9) the Public Land Survey system. Intermediate DLG's taken from 30- by 60-minute quadrangle maps include five categories: (1) the Public Land Survey system, (2) boundaries, (3) transportation, (4) hydrography, and (5) hypsography. The small-scale DLG's are acquired from such maps as the USGS 1:2,000,000 sectional maps of the National Atlas and have three categories: (1) boundaries, (2) transportation, and (3) hydrography.

Digital Raster Graphic (DRG)

DRG is a scanned image of a USGS topographic map. Each image is georeferenced to Universal Transverse Mercator (UTM) ground coordinates. Production of DRG's for the contiguous United States was completed in 1998. The USGS is replicating the 1:24,000, 1:24,000/1:25,000, 1:63,360 (Alaska), 1:100,000, and 1:250,000 scale topographic map series. DRG's are being used to collect new data, revise DLG's, and validate other digital data sources.

Land Use and Land Cover (LULC)

The USGS has compiled LULC data and associated maps into a single digital data set. There are six categories of data: (1) LULC, (2) political units, (3) hydrologic units, (4) census county subdivisions, (5) Federal land ownership, and (6) State land ownership. Within the LULC category, there are nine classes of data: (1) urban or built-up land, (2) agricultural land, (3) rangeland, (4) forest land, (5) water, (6) wetland, (7) barren land, (8) tundra, and (9) perennial snow or ice. This data can be obtained in two formats: vector polygon or composite theme grid cell. In the vector polygon, all topographic elements are represented as points, lines, or areas. The composite theme grid cell is divided into 4-hectare (10-acre) cells. Associated with each cell is series of codes to identify the appropriate attribute.

Digital Orthophoto Quadrangles (DOQ)

DOQ's combine the image characteristics of a photograph with the geometric qualities of a map. Wirth et al. (1994b) describe the creation of DOQ's as a process of scanning aerial photographs with each pixel of the image being corrected for relief displacement and camera orientation through georectification. There are four inputs required for DOQ's: (1) accurate control points, (2) camera calibration and orientation parameters, (3) a DEM, and (4) a scanned image of the aerial photograph(s) to be georectified. For example, DOQ's are valuable data sources for updating road and land cover data bases developed from Landsat TM data.

Cartographic Feature Files (CFF)

A CFF is a digital file containing a vector representation of the point and line features shown on a Forest Service Primary Base Series (PBS) map. The Geometronics Service Center (GSC) produces CFF's for lands administered by the Forest Service. CFF's are formatted according to the USGS quadrangle convention. The feature categories contained in the CFF are (1) transportation, (2) streams and water bodies, (3) political and administrative boundaries, (4) land ownership, and (5) other cultural features.

Planned Sensors

Over the past couple of years and into the next decade, several countries and private aerospace companies have launched or will be launching their own satellites (table 10.1 and table 10.2). These sensors have much higher spatial resolutions and stereo capabilities, and many are capable of gathering data in panchromatic and multispectral modes. In addition, hyperspectral sensors, which gather reflectance data in several hundred wavebands, have much finer spectral resolutions as well.

These "next generation" sensors will provide many exciting new opportunities for research and applications to support ecosystem management activities at all scales of analysis. The much improved spatial and spectral resolutions, and therefore increased information content, of these sensors should enhance vegetation mapping, fire modeling, and wildlife habitat analysis.

The following provides brief descriptions of a representative sample of the many new sensors coming on-line.

Landsat 7

One sensor of particular interest is the Enhanced Thematic Mapper Plus (ETM+) aboard Landsat 7, scheduled for launch in December 1998. This new instrument will have the same capabilities as the TM sensor on Landsat 4 and 5, with some additional features:

- ▶ A panchromatic band with 15-meter spatial resolution;
- ▶ On-board, full aperture, 5-percent absolute radiometric calibration; and
- ▶ A thermal IR channel with 60-meter spatial resolution.

With these changes, the ETM+ will be better suited for global change studies, land cover monitoring and assessment, and large area mapping than previous instruments. Within 24 hours after acquisition of an image, users will be able to view a low-resolution, noncorrected image and metadata to determine quality and information. Radiometric and geometric corrected data will be generated upon request.

Multispectral

Band	Spectral Resolution (µm)	Spectral Location
1	0.45 - 0.52	Blue
2	0.52 - 0.60	Green
3	0.63 - 0.69	Red
4	0.76 - 0.90	Near IR
5	1.55 - 1.75	Mid IR
6	2.08 - 2.35	Mid IR

- ▶ Spatial Resolution: 30 m
- ▶ Temporal Resolution: 16 days
- ▶ Swath: 185 km

Multispectral Thermal

Band	Spectral Resolution (µm)	Spectral Location
1	8.20 - 8.75	Thermal IR
2	8.75 - 9.30	Thermal IR
3	10.2 - 11.0	Thermal IR
4	11.0 - 11.8	Thermal IR

- ▶ Spatial Resolution: 60 m
- ▶ Temporal Resolution: 16 days
- ▶ Swath: 185 km

Short Wave Thermal

Band	Spectral Resolution (µm)	Spectral Location
1	3.53 - 3.93	Thermal IR

- ▶ Spatial Resolution: 120 m
- ▶ Temporal Resolution: 16 days
- ▶ Swath: 185 km

Panchromatic

Band	Spectral Resolution (µm)	Spectral Location
1	0.50 - 0.90	Green - Red

- ▶ Spatial Resolution: 15 m
- ▶ Temporal Resolution: 16 days
- ▶ Swath: 185 km

(Adapted from www.ccrs.nrcan.gc.ca/ccrs/tekrd/satsens/sats/landsate.html#landsat7)

Space Imaging

Space Imaging's 1-meter satellite, IKONOS 1, is scheduled for launch in 1998. IKONOS 1 is designed to take both black-and-white images with 1-meter resolution and multispectral images with 4-meter resolution. The satellite incorporates a key color-enhancing algorithm that allows multispectral information to achieve 1-meter sharpness. In addition, a near-infrared band at 4-meter resolution will also be collected. (From www.spaceimaging.com)

Table 10.1. *Earth Observation Satellites: Current. Includes those satellites which are currently operational. It is limited to sensors which are primarily intended for remote sensing of the Earth surface.*

Satellite Name	Source	Launch	Sensors	Types	No. of Channels	Resolution (meters)
Landsat-5	US	1984	MSS	Multispectral	4	82
			TM	Multispectral	6	30
					1	120
IRS-1A	India	1988	LISS-I	Multispectral	4	72.5
			LISS-II	Multispectral	4	36.25
SPOT-2	France	1990	HRV	Multispectral	3	20
				Panchromatic	1	10
IRS-1B	India	1991	LISS-I	Multispectral	4	72.5
			LISS-II	Multispectral	4	36.25
NOAA-12	US	1991	AVHRR	Multispectral	5	1100
ERS-1	ESA	1991	AMI	Radar	1	26
			ATSR	Multispectral	4	1000
JERS-1	Japan	1992	SAR	Radar	1	18
			OPS	Multispectral	7	18 x 24
SPOT-3	France	1993	HRV	Multispectral	3	20
				Panchromatic	1	10
RESURS-01-3	Russia	1994	MSU-SK	Multispectral	4	170
					1	600
NOAA-14	US	1994	AVHRR	Multispectral	5	1100
IRS-1C	India	1995	WiFS	Multispectral	2	188
			LISS-III	Multispectral	3	23
					1	70
			Pan	Panchromatic	1	5.8
ERS-2	ESA	1995	AMI	Radar	1	26
			ATSR	Multispectral	4	1000
RADARSAT	Canada	1995	SAR	Radar	1	9 - 100
OrbView-2 (SeaStar)	US/Orbimage	1997	SeaWiFS	Multispectral	8	1130
IRS-ID	India	1997	WiFS	Multispectral	2	188
			LISS-III	Multispectral	3	23
					1	70
			Pan	Panchromatic	1	5.8
SPIN-2	US/Russia	1997	KVR-1000	Panchromatic	1	2
			TK-350	Panchromatic	1	10
SPOT-4	France	1998	VI	Multispectral	4	1150
			HRV	Multispectral	4	20
				Panchromatic	1	10

Adapted from www.ersc.wisc.edu

Table 10.2. *Earth Observation Satellites: Future. Includes those satellites which are proposed for future launch. It is limited to sensors which are primarily intended for remote sensing of the Earth surface.*

Satellite Name	Source	Launch	Sensors	Types	No. of Channels	Resolution (meters)
NOAA-K	US	1998	AVHRR	Multispectral	5	1100
IKONOS	Space Imaging/EOSAT	1998	Space Imaging	Multispectral	4	4
				Panchromatic	1	1
CBERS	China/Brazil	1998	CCD	Multispectral	5	20
			IRMSS	Multispectral	3	80
					1	160
EOS AM-1	US	1998	ASTER	Multispectral	14	15, 30, 90
			MISR	Multispectral	4	275
			MODIS	Multispectral	36	250, 500, 1000
Landsat-7	US	1999+	ETM+	Multispectral	6	30
					1	60
				Panchromatic	1	15
QuickBird	EarthWatch	1998	Multispectral	Multispectral	4	3.2
			Panchromatic	Panchromatic	1	0.82
EROS-A	West Indian Space, Ltd.	1998	Panchromatic	Panchromatic	1	1.5
EROS-B1	West Indian Space, Ltd.	1998	Panchromatic	Panchromatic	1	0.82
IKONOS 2	Space Imaging	1998	Space Imaging	Multispectral	4	4
				Panchromatic	1	1
Resource 21-A, B, C, D	Resource 21	1999-2000	Multispectral	Multispectral	5	10, 20
			Cirrus	Multispectral	1	100+
NOAA-L	US	1999	AVHRR	Multispectral	5	1100
OrbView-3	Orbimage	1999	OrbView	Multispectral	4	4
				Panchromatic	2	1 - 2
LightSAR	US	2001	SAR	Radar	4	3 - 100
ADEOS-II	Japan	1999	GLI	Multispectral	34	250 - 1,000
EO-1	US	1999	ALI	Panchromatic	1	10
				Multispectral	6	30
				Hyperspectral	542	30
			LAC	Multispectral	1	250
ENVISAT-1	ESA	1999	ASAR	Radar	1	30, 150
			MERIS	Multispectral		
IRS-P5	India/US	1999	Pan	Panchromatic	1	2.5
EOS PM-1	US	2000	MODIS	Multispectral	36	250 - 1000
OrbView-4	Orbimage	2000	OrbView-4	Hyperspectral	280	8

Table 10.2. (continued) *Earth Observation Satellites: Future. Includes those satellites which are proposed for future launch. It is limited to sensors which are primarily intended for remote sensing of the Earth surface.*

Satellite Name	Source	Launch	Sensors	Types	No. of Channels	Resolution (meters)
ALOS	Japan	2002	VSAR	Radar	1	10
			AVNIR-2	Multispectral	4	10
				Panchromatic	1	2.5
ARIES	Australia	2000	ARIES-1	Panchromatic	1	12
				Multispectral	96	12, 30
HRST	US	2000	HRST/COIS	Multispectral	210	30
			PIC	Panchromatic	1	5
IRS-P6	India/US	2000	LISS IV	Multispectral	7	6, 23.5
			AwiFS	Multispectral	3	80
NOAA-M	US	2001	AVHRR	Multispectral	5	1100
XSTAR	France/Great Britain	2001	XSTAR	Multispectral	10+	20
SPOT-5	France	2001	HRV	Multispectral	3	10
					1	20
				Panchromatic	1	5
			VI	Multispectral	4	1150
EOS AM-2	US	2004	LATI	Multispectral		
			AMISR	Multispectral		
			AMODIS	Multispectral		

Adapted from www.ersc.wisc.edu

Appendix B

Glossary of Selected Remote Sensing Terminology

accuracy assessment — process by which the accuracy or correctness of an image classification is evaluated

ancillary data — in remote sensing, the secondary data pertaining to the area or classes of interest, used to help correctly classify an image

canopy structure — vertical structure of the vegetation, single story or multistory

cartographic feature files — digital data file containing a vector representation of the point and line features shown on a Forest Service Primary Base Series map

data dictionary — technical information necessary to construct a GIS layer such as database table formats, attribute "column" definitions, spatial coverage tolerances, and so forth

digital elevation model — digital data file containing an array of elevation information over a portion of the Earth's surface

digital orthophoto quad — digital representation of an aerial photo with ground features located in their "true" positions

divergence matrices — a statistical measure of spectral distance between two or more signatures

error matrix — table used as a starting point for a series of descriptive and analytical statistical techniques for accuracy assessment

geographic information system (GIS) — system for capturing, storing, checking, manipulating, analyzing, and displaying geospatial data

geometric correction — an image preprocessing technique that reorients the image data to compensate for the Earth's rotation and variations in satellite position and attitude

GIS Core Data — minimum GIS layers required for complete and consistent geospatial information across all Forest Service lands

metadata — data used to describe geospatial data sets

multispectral — refers to sensors (or images) that record (or display) data from two or more bands of the electromagnetic spectrum

multivariate classification — data from the various spectral bands and other sources (such as DEM) are utilized simultaneously

panchromatic — refers to single-band imagery

percent crown closure — area covered by the vegetation canopy

pixel — picture element

principal components — an image preprocessing technique used to minimize spectral redundancy by compressing the dimensionality of the data

radiometric correction — an image preprocessing technique to adjust for influence from scene illumination, atmospheric conditions, viewing geometry, and instrument response characteristics

remote sensing — gathering of data about an object or event from a distance

signature plot — graphic representation of where a spectral signature is located in relation to the values of each spectral band

supervised classification — a method of image classification that depends upon the direct involvement of the analyst in the pattern recognition process (see also unsupervised classification)

tasseled cap transformation — an image preprocessing technique that optimizes data viewing for vegetation studies

terrain correction — an image preprocessing technique that corrects for the distortion resulting from recording a 3-D view in two dimensions

training sites — geographic area represented by the pixels selected to represent a particular class

tree size class — diameter of the trees that constitute the dominant or overstory canopy

unsupervised classification — a computer-automated method of spectral pattern recognition, in which some parameters are specified by the user and used to uncover statistical patterns inherent in the image data (see also supervised classification)

vegetation composition — species groups or associations that constitute the dominant or overstory canopy

Appendix C

Acronyms

AVHRR	Advanced Very High Resolution Radiometer
CALVEG	Classification and Assessment with Landsat of Visible Ecological Groups
CCD	Charged Coupled Device
CDF	California Department of Forestry
CTO	Corporate Training Office
CVU	Common Vegetation Unit
DEM	Digital Elevation Model
DLG	Digital Line Graph
DOD	Department of Defense
DOQ	Digital Orthophoto Quadrangle
DRG	Digital Raster Graphics
EDC	Earth Resources Observation System Data Center
ERS	Earth Resource Satellite
ESA	European Space Agency
FGDC	Federal Geographic Data Committee
FHTET	Forest Health Technology Enterprise Team
FIA	Forest Inventory and Analysis
FLIR	Forward Looking Infrared Radar
FPM	Forest Pest Management Program
FRAP	Fire and Resource Assessment Program
GAP	Gap Analysis Program
GIS	Geographic Information System
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GSC	Geometronics Service Center
HRV	High Resolution Visible
IREMCG	Interregional Ecosystem Management Coordinating Group
IRI	Integrated Resource Inventory
IRS	Indian Remote Sensing
JERS	Japanese Earth Resources Satellite
LAA	Large Area Assessment
LU/LC	Land Use/Land Cover
MMU	Minimum Mapping Unit
MRLC	Multi-Resolution Land Characteristics Consortium
MSS	Multispectral Scanner
NAPP	National Aerial Photography Program
NASA	National Aeronautics and Space Administration
NFAP	National Forestry Applications Program
NHAP	National High Altitude Photography
NRCS	Natural Resources Conservation Service
NSDI	National Spatial Data Infrastructure
NVCS	National Vegetation Classification System
RPA	Forest and Rangeland Renewable Resources Planning Act
RSAC	Remote Sensing Applications Center
RSSC	Remote Sensing Steering Committee
SA	Selective Availability
SAR	Synthetic Aperture Radar
SLAR	Side-Looking Airborne Radar
SPOT	Système Pour l'Observation de la Terre
THP	Timber Harvesting Plan
TIROS	Television and Infrared Observation Satellite
TM	Thematic Mapper
TNC	The Nature Conservancy
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USGS	United States Geological Survey
UTM	Universal Transverse Mercator

Appendix D

Examples of Vegetation Types Organized Within the National Vegetation Classification System (NVCS) Hierarchy

NVCS Hierarchy	Example Classification
DIVISION	Vegetated
ORDER	Tree Dominated
PHYSIOGNOMIC CLASS	Closed Tree Canopy
PHYSIOGNOMIC SUBCLASS	Evergreen
PHYSIOGNOMIC GROUP	Temperate or Subpolar Needle-leaved
SUBGROUP	Natural/Seminatural
FORMATION	Rounded Crowns
ALLIANCE	*Pinus taeda* Closed Tree Canopy Alliance
ASSOCIATION	*Pinus taeda/Symplocos tinctoria-Myrica cerifera-Vaccinium elliotii*
DIVISION	Vegetated
ORDER	Tree Dominated
PHYSIOGNOMIC CLASS	Closed Tree Canopy
PHYSIOGNOMIC SUBCLASS	Evergreen
PHYSIOGNOMIC GROUP	Temperate or Subpolar Needle-leaved
SUBGROUP	Planted/Cultivated
FORMATION	Tree Plantation
ALLIANCE	Loblolly Pine *(Pinus taeda)* Plantation
DIVISION	Vegetated
ORDER	Shrub Dominated
PHYSIOGNOMIC CLASS	Shrubland
PHYSIOGNOMIC SUBCLASS	Evergreen
PHYSIOGNOMIC GROUP	Macrophyllous evergreen shrub
SUBGROUP	Planted/Cultivated
FORMATION	Fruit/leaf/nut shrub crop
ALLIANCE	Cultivated Cranberry *(Vaccinium macrocarpon)* Bog

NVCS Hierarchy	Example Classification
DIVISION	Vegetated
ORDER	Herbaceous/Nonvascular Dominated
PHYSIOGNOMIC CLASS	Herbaceous
PHYSIOGNOMIC SUBCLASS	Perennial Graminoid
PHYSIOGNOMIC GROUP	Temperate or Subpolar
SUBGROUP	Natural/Seminatural
FORMATION	Temperate tall dense sod grassland
ALLIANCE	*Andropogon gerardii-Panicum virgatum* Alliance
ASSOCIATION	*Andropogon gerardii-Panicum virgatum-(Spartinapatens)*
DIVISION	Vegetated
ORDER	Herbaceous/Nonvascular Dominated
PHYSIOGNOMIC CLASS	Herbaceous
PHYSIOGNOMIC SUBCLASS	Annual Graminoid
PHYSIOGNOMIC GROUP	Temperate
SUBGROUP	Planted/Cultivated
FORMATION	Row Crop
ALLIANCE	Corn *(Zea mays)* Crop
DIVISION	Vegetated
ORDER	No dominant life form
PHYSIOGNOMIC CLASS	Sparsely vegetated
PHYSIOGNOMIC SUBCLASS	Gravel, cobble rocks
PHYSIOGNOMIC GROUP	Rock flats
SUBGROUP	Natural/Seminatural
FORMATION	Pavement
ALLIANCE	*Sedum nuttallianum* Alliance
ASSOCIATION	*Sedum nuttallianum-Selaginella peruviana*

(Adapted from biology.usgs.gov/fgdc.veg/standards/appendix2.htm)

Appendix E

Anderson Land Use/Land Cover Classification System

Level I		Level II	
Code	**Class Name**	**Code**	**Class Name**
1	**Urban or Built-up Land**[1]	**11**	**Residential**
		12	**Commercial and Services**
		13	**Industrial**
		14	**Transportation, Communications, and Utilities**
		15	**Industrial and Commercial Complexes**
		16	**Mixed Urban or Built-up Land**
		17	**Other Urban or Built-up Land**
2	Agricultural Land	21	Cropland and Pasture
		22	Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
		23	Confined Feeding Operations
		24	Other Agricultural Land
3	Rangeland	31	Herbaceous Rangeland
		32	Shrub and Brush Rangeland
		33	Mixed Rangeland
4	Forest Land	41	Deciduous Forest Land
		42	Evergreen Forest Land
		43	Mixed Forest Land
5	**Water**	**51**	**Streams and Canals**
		52	**Lakes**
		53	**Reservoirs**
		54	**Bays and Estuaries**
6	Wetland	61	Forested Wetlands
		62	Nonforested Wetlands
7	**Barren Land**	**71**	**Dry Salt Flats**
		72	**Beaches**
		73	**Sandy Areas Other than Beaches**
		74	**Bare Exposed Rock**
		75	**Strip Mines, Quarries, and Gravel Pits**
		76	**Transitional Areas**
		77	**Mixed Barren Land**
8	Tundra	81	Shrub and Brush Tundra
		82	Herbaceous Tundra
		83	Bare Ground
		84	Wet Tundra
		85	Mixed Tundra
9	Perennial Snow or Ice	91	Perennial Snowfields
		92	Glaciers

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[1] Labels in bold are recommended to describe nonvegetative attributes

Appendix F

Proposed Forest Service Image Processing System

Digital remotely sensed data are used increasingly throughout the Forest Service to create, expand, and update geospatial data bases. Processing remotely sensed data is very computer intensive and requires resources above and beyond a standard GIS configuration. To meet the growing needs in the Forest Service, a standard image processing technology will be implemented Service-wide on the IBM platform. The image processing software requires a minimum of 96 MB RAM, 250 MB swap space, and up to 250 MB hard disk space for installation and operations. Two user configurations are planned: basic and advanced.

Image Processing Configuration

Basic User Configurations
This configuration will perform basic image processing tasks, including digital image data display, data import and export, map registration, cartographic composition, data manipulation, data transformations, rectification and restoration, basic classification, basic statistics, and map projections.

This basic configuration is intended for users who have limited experience in remote sensing/image processing technology. It is also designed to complement the tools available with the GIS software on the IBM contract and will be available to each national forest. Although the image processing software can run on a smaller server, it is strongly recommended that it be loaded on an RS/6000 Model 595 or server to more efficiently process large data sets. X-terminals for image processing should be upgraded from the standard 12 MB RAM to 28 MB RAM.

Advanced User Configuration
The advanced configuration will perform all the functions of the basic system and offer even more capability. This configuration includes capabilities to perform advanced satellite classification and includes additional modules to process radar and hyperspectral data. It also provides additional tools for raster analysis, ortho rectification, terrain modeling, texture analysis, mosaicking, satellite ortho correction, transformation, spatial modeling, and advanced classification functions.

This advanced system offers two workstation options and is intended for users who have considerable knowledge of remote sensing/image processing technology. It is designed for sites that need to process large amounts of data on a production basis. The two options are a low-end and a high-end workstation.

The model 140 workstation includes:
- RS/6000 Model 43P workstation with 200-MHz processor.
- 128 MB RAM, which can be upgraded to 768 MB.
- 9.1-GB hard drives.
- 20-inch monitor.
- CD-ROM and diskette drive.

The model 240 workstation includes:
- RS/6000 Model 43P workstation with dual 200-MHz processors.
- 256 MB RAM, which can be upgraded to 1 GB RAM.
- 18.2-GB hard drive.
- 20-inch monitor.
- CD-ROM and diskette drive.

Tape drives, up to 200-GB tape towers, disk array, and other devices are also available for either workstation.

Appendix G

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Appendix I

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